Guidebook to Constructing Inexpensive Science Teaching Equipment Volumes 1-3

Published by:
The International Clearinghouse on Science and Mathematics Curriculum Developments
Science Teaching Center
University of Maryland
College Park, MD 20742 USA

Paper copies are $10.00 for the set of three volumes.

Available from:
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GUIDEBOOK TO CONSTRUCTING INEXPENSIVE SCIENCE TEACHING EQUIPMENT

Volume I: Biology

Inexpensive Science Teaching Equipment Project
Science Teaching Center
University of Maryland, College Park
U.S.A.

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Inexpensive Science Teaching Equipment Project
Science Teaching Center
University of Maryland

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Volume I, Biology

Volume II, Chemistry

Volume III, Physics

The following table refers only to the contents of this volume, but the listing at the back of each volume provides an alphabetical index to all three volumes.

References within the text normally indicate the volume, chapter and number of the item referred to (e.g., PHYS/V/A3), but where a reference is to an item within the same volume, the reference indicates only the chapter and number of the item (e.g., V/A3).

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FOREWORD

History

The Inexpensive Science Teaching Equipment Project was initiated by Dr. J. David Lockard, and got underway under his direction in the summer of 1968. Originally entitled the Study of Inexpensive Science Teaching Equipment Worldwide (IS-TEW or IS-2 Study), the Project was to (1) identify laboratory equipment considered essential for student investigations in introductory biology, chemistry and physics courses in developing countries; (2) improvise, wherever possible, equivalent inexpensive science teaching equipment; and (3) produce designs of this equipment in a Guidebook for use in developing countries. Financial support was provided by the U.S. Agency for International Development through the National Science Foundation.

The initial work of the Project was undertaken by Maria Penny and Mary Harbeck under the guidance of Dr. Lockard. Their major concern was the identification of equipment considered basic to the teaching of the sciences at an introductory level. An international survey was conducted, and a list of equipment to be made was compiled. A start was also made on the writing of guidelines (theoretical designs) for the construction of equipment.

Work on the development of the Guidebook itself got underway in 1970, with the arrival of Reginald F. Melton to coordinate the work. Over 200 guidelines were completed during the year by Donald Urbancic (Biology), Chada Samba Siva Rao and John Delaini (Chemistry), and Reginald Melton (Physics). Full use was made of project materials from around the world which were available in the files of the International Clearinghouse on Science and Mathematics Curricular Developments, which is located in the Science Teaching Center of the University of Maryland. The guidelines were compiled into a draft edition of the Guidebook which was circulated in September, 1971, to some 80 science educators around the world for their comments and advice.

The work of constructing and developing equipment from the guidelines, with the subsequent production of detailed designs, began in a limited way in 1970, the major input at that time being in the field of chemistry by Chada Samba Siva Rao, who was with the project for an intensive two-month period. However, the main work of developing detailed designs from the guidelines was undertaken between 1971 and 1972 by John Delaini (Biology), Ruth Ann Butler (Chemistry) and Reginald Melton (Physics). Technical assistance was given by student helpers, with a special contribution from David Clark, who was with the project for a period of 18 months.

Thanks are due to those graduates, particularly Samuel Genova, Melvin Soboleski and Irven Spear, who undertook the development of specific items of equipment while studying at the Center on an Academic Year Institute program; to student helpers, especially Don Kallgren, Frank Cathell and Theodore Mannekin, who constructed the equipment; and to Dolores Aluise and Gail Kuehnle who typed the manuscripts.

Last, but not least, special acknowledgement is due to those individuals, and organizations, around the world who responded so willingly to the questionnaires in 1968 and to the draft edition of the Guidebook in 1971.

The Guidebook

The designs presented in the Guidebook are based on the premise that many students and teachers in developing countries will wish to make equipment for themselves. This does not mean that students and teachers are expected to produce all their own apparatus requirements. It is recognized that teachers have specific curricula to follow, and that "class hours" available for such work are very limited. It is also recognized that teachers, particularly those in developing countries, are not well paid, and often augment their salaries with supporting jobs, thus placing severe limits on the "out-of-class hours" that are available for apparatus production.

However, in designing equipment for production by students and teachers, two factors have been kept in mind. One, project work in apparatus development can be extremely rewarding for students, bringing both students and teachers into close contact with the realities of science, and relating science and technology in the simplest of ways. Two, it is not difficult for cottage (or small scale) industries to adapt these designs to their own requirements. The Guidebook should therefore not only be of value to students and teachers, but also to cottage industries which may well be the major producers of equipment for schools.

Although all the designs in the Guidebook have been tested under laboratory conditions in the University of Maryland, they have not been tested in school situations nor produced and tested under local conditions in developing countries. It is therefore recommended that the designs should be treated primarily as limited resource materials to be subjected to trial and feedback. It is suggested that the first time that an item is constructed it should be made precisely as described in the Guidebook, since variations in the materials, or the dimensions of the materials, could alter the characteristics of the apparatus. However, once this item has been tested the producer is encouraged to make any number of modifications in the design, evaluating the new products against the original.

Before producing new equipment in quantity, it is recommended that educators with experience in the field of science education should be involved in determining how best to make use of the Guidebook. They will wish to relate the apparatus to their own curriculum requirements, and, where necessary, prepare relevant descriptions of experiments which they recommend should be undertaken using the selected apparatus. They will want to subject the experiments and related equipment to trials in school situations. Only then will they consider large-scale production of apparatus from the designs in the Guidebook. At this stage educators will wish to control the quality of apparatus production, to train teachers to make the best use of the new apparatus, and to insure that adequate laboratory conditions are developed to permit full utilization of the apparatus. Too often in the past apparatus has sat unused on many a classroom shelf, simply because the teacher has been untrained in its usage, or the laboratory facilities have been inadequate, or because the apparatus available did not appear to fit the requirements of the existing curriculum. Such factors are best controlled by educators in the field of science education in each country. Clearly the science educator has a crucial role to play.

Apparatus development, like any aspect of curriculum development, should be considered as a never ending process. This Guidebook is not presented as a finished product, but as a part of this continuing process. There is no doubt that the designs in this book could usefully be extended, descriptions of experiments utilizing the apparatus could be added, and the designs themselves could be improved. No extravagant claims are made concerning the Guidebook. It is simply hoped that it will contribute to the continuing process of development.

TOOLS AND RAW MATERIALS

The raw materials required to make specific items of equipment are indicated at the beginning of each item description. However, there are certain tools and materials which are useful in any equipment construction workshop, and these are listed below.

Tools

Chisels, Wood

3, 6, 12, 24 mm
(i.e., 1/8", 1/4", 1/2", 1")

Cutters

Bench Shears: 3 mm (1/8") capacity
Glass Cutter
Knife
Razor Blades
Scissors: 200 mm (8")
Snips (Tinmans), Straight: 200 mm (8")
Snips (Tinmans), Curved: 200 mm (8")
Taps and Dies: 3 to 12 mm (1/8" to 1/2") set

Drills and Borers

Cork Borer Set
Countersink, 90°
Metal Drill Holder (Electrically Driven), Capacity 6 mm (1/4")
Metal Drills: 0.5, 1, 2, 3, 4, 5, 6, 7 mm
(i.e., 1/32", 1/16", 3/32", 1/8", 5/32", 3.16", 7/32", 1/4") set
Wood Brace with Ratchet: 250 mm (10")
Wood Auger, Bits: 6, 12, 18, 24 mm
(i.e., 1/4", 1/2", 3/4", 1")

Files, Double Cut

Flat: 100 mm, 200 mm (4", 8")
Round: 100 mm, 200 mm (4", 8")
Triangular: 100 mm (4")

Hammers

Ball Pein: 125, 250, (1/4, 1/2 lb)
Claw 250 g (1/2 lb)

Measuring Aids

Caliper, Inside
Caliper, Outside
Caliper, Vernier (may replace above two items)
Dividers: 150 mm (6"), Toolmakers
Meter, Electrical (Multipurpose - volts, ohms, amps, etc.)
Meter Stick
Protractor
Scriber

Measuring Aids (Continued)

Set Square
Square, Carpenter's: 300 mm (12") blade
Spoke Shave: 18 mm (3/4")
Wood Smoothing Plane

Pliers

Combination: 150 mm (6")
Needle Nose: 150 mm (6")
Side Cutting: 150 mm (6")
Vise Grips

Saws, Metal

300 mm (12") blades

Saws, Wood

Back Saw: 200, 300 mm (8", 12")
Coping Saw: 200 mm (8")
Cross Cut: 600 mm (24")
Hand Rip: 600 mm (24")
Key Hole Saw: 200 mm (8")

Screw Drivers

100 mm (4"), with 2 and 3 mm tips
150 mm (6"), with 5 mm tip
200 mm (8"), with 7 mm tip

Vise

Metal Bench Vise: 75 mm (3")
Wood Bench Vise: 150 mm (6")

Miscellaneous

Asbestos Pads
Goggles, Glass
Oil Can: 1/2 liter (1 pint)
Oil Stone, Double Faced
Punch, Center
Sandpaper and Carborundum Paper, Assorted grades
Soldering Iron: 60 watts, 100 watts

Raw Materials

Adhesives

All Purpose Cement (Elmers, Duco)
Epoxy Resin & Hardener (Araldite)
Rubber Cement (Rugy)
Wood Glue (Weldwood)
Cellophane Tape
Plastic Tape
Masking Tape

Electrical Materials

Bulbs with Holders: 1.2, 2.5, 6.2 volts
Dry Cells: 1.5, 6 volts
Electrical Wire: Cotton or Plastic covered
Fuse Wire: Assorted
Lamps: 50, 75, 100 watts
*Magnet Wire: #20, 22, 24, 26, 28, 30, 32, 34
Nichrome Wire: Assorted
Parallel Electrical Cording
Plugs
Switches

Glass and Plastic

Acrylic (Plastic) Sheets: 2 cm and 2.5 cm thick
Plates, Glass
Tubes, Glass: 3, 6 mm (1/8", 1/4") internal diameter

Hardware

Bolts and Nuts, Brass or Steel; 3 mm (1/8") diameter: 12, 24, 48 mm (1/2", 1", 2") lengths
Nails: 12, 24 mm (1/2", 1") lengths
Screws, Eye
Screws, Wood: 12, 18, 24, 26 mm (1/2", 3/4", 1", 1 1/2") lengths
Thumbtacks
Washers (Brass and Steel): 6, 9 mm (1/4", 5.16") diameter
Wingnuts (Steel): 5 mm (3/16")

Lumber

Boxwood (Packing Case Material)
Hardboard: 6 mm (1/4") thick
Kiln Dried Wood: 2.5 x 15 cm (1" x 6") cross section
1.2 x 15 cm (1/2" x 6") cross section
Plywood: 6, 12 mm (1/4", 1/2") thickness
Wood Dowels: 6, 12 mm (1/4", 1/2") thickness

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* U.S. Standard Plate numbers are used in this book to indicate the gauge of different wires. Where wires are referenced against other numbering systems appropriate corrections should be make in determining the gauges of materials required. The following comparison of gauges may be of interest:

Standard	Diameter of #20 Wire
Brown & Sharp	0.08118
Birmingham or Stubs	0.089
Washburn & Moen	0.0884
Imperial or British Standard	0.0914
Stubs' Steel	0.409
U. S. Standard Plate	0.09525

Metal Sheets

Aluminum: 0.2, 0.4 mm (1/100", 1/64") thickness.
Brass: 0.4, 0.8 mm (1/64", 1/32") thickness.
Galvanized Iron: 0.4 mm (1/64") thickness.
Lead: 0.1 mm (1/250") thickness.
Spring Steel, Packing Case Bands

Metal Tubes:

Aluminum, Brass Copper: 6, 12 mm (1/4", 1/2") internal diameter.

Metal Wires

Aluminum: 3 mm (1/8") diameter
Coathanger: 2 mm (1/16") diameter
*Copper: #20, 24
Galvanized Iron: 2 mm (1/16") diameter
*Steel: #20, 26, 30.

Paint Materials

Paint Brushes
Paint Thinner
Varnish
Wood Filler

Miscellaneous

Aluminum Foil
Cardboard Sheeting
Containers (Plastic or Glass)
Corks (Rubber or Cork)
Grease
Hinges: Assorted
Machine Oil
Marbles
Mesh (Cotton, Nylon, Wire)
Modelling Clay (Plasticene)
Paper Clips
Pens: Felt (Marking Pens)
Pins and Needles
Rubber Bands
Soldering Lead
Soldering Paste
Spools
Steel Wool
Straws
String (Cord, Cotton, Nylon)
Styrofoam
Syringes: Assorted
Wax (Paraffin)

*See footnote on previous page.

I. MAGNIFIERS AND MICROSCOPES

A. MAGNIFIERS

Magnifiers are used for low power magnification. The three included here can be employed wherever it is desirable to see a little more detail than is obtainable with the naked eye.

B. MICROSCOPES

Where high power magnification is needed, microscopes can be used. The ones in this section can, for the most part, be adapted to use water drop, glass bead, or penlight bulb lenses. Magnifications up to around 60X - 80X may be gotten using these microscopes. All are designed for use with freshly and/or permanently mounted glass slides.

C. SUPPLEMENTARY APPARATUS

These items are essential for preparing the slides to be viewed with the microscopes.

A. MAGNIFIERS

A1. Water Filled Magnifier

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Flask	1	Spherical Body Flask (A)	50-500 ml

b. Construction

(1) Flask

Simply fill the flask (A) with clear water up to the neck.

c. Notes

(i) A 250 ml flask (about 7.5 cm in diameter) will magnify approximately the same as a double convex magnifying glass 4 cm in diameter and 0.7 cm in thickness.

(ii) Smaller diameter flasks appear to magnify more than larger diameter ones.

A2. Water Bulb Magnifying Glass *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Water Bulb Magnifying Glass	1	Glass Tubing (A)	0.3 cm diameter, 10-13 cm long

b. Construction

(1) Water Bulb Magnifying Glass

Use a Bunsen Burner or gas burner and fuel system (CHEM/II/C1 and 2) as a heat source. Follow the glass-blowing instructions (CHEM/I/D6) and blow at one end of the glass tube (A) a bulb of about 0.8 cm diameter.

Provide a glass or cup of water and a wooden clothespin, pinch clamp (CHEM/IV/A4) or a few square centimeters of cloth to serve as a holder.

Rotate the bulb near, but not in, the flame to expand the air in the bulb.

*Adapted from James E. Hammesfahr and Claire L. Strong, Creative Glassblowing, (San Francisco: W. H. Freeman and Company, 1964), pp 108-9.

After a few seconds of heating, quickly invert the piece and put the open end into the water. Allow the piece to remain in the water a few seconds. The air in the bulb contracts and water is drawn up into the tube.

Remove the piece from the water and hold it, bulb down, in one hand near the open end of the tube. Lightly flick the bulb with the index finger of the other hand. Continue flicking until the water has gone from the tube into the bulb.

Next, grasp the tube with the clothespin, pinch clamp, or folded cloth, and again hold the bulb close to the flame until the water boils. Point the open end of the tube away from yourself and anyone else.

Heat the bulb while steam escapes from the tube for about 5 seconds. Then quickly invert the tip of the tube into the water. Allow the tube to remain in the water until the bulb is full, or nearly full, of water. If after a few minutes, the bulb has not filled with water, repeat the heating and filling process.

Remove the piece from the water and invert it so that any air remaining in the bulb can enter the tube. Flick the bulb, as before, and the bubble will rise to the open end of the tube.

Holding the bulb with the tube upright, heat the end of the tube in the hottest part of the flame to seal the tip. As the tip seals, the expanding air of the trapped bubble blows a tiny bulb at the end of the tube.

c. Notes

(i) The first heating of the bulb expands the air, which, when it contracts, draws a small amount of water into the bulb. Converting this water into steam expels all the air and causes the bulb to fill completely with water as the steam condenses.

(ii) When this water-filled bulb is held about 0.5 cm from an object, the object will appear distorted around the edges, but clear and greatly enlarged at the center of the bulb.

A3. Illuminated Hand Magnifier

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Eyepiece	1	Double Convex Lens (A)	2.5 cm diameter
	1	Single Convex Lens (B)	2.5 cm diameter
	1	Cardboard Tube (C)	5 cm long, 2.5 cm inside diameter
	1	Cardboard Tube (D)	5 cm long, 2.8 cm inside diameter
(2) Adaptor	1	Cardboard Tube (E)	5 cm long, 3.5 cm inside diameter
(3) Barrel	1	1.5 Volt Penlight Bulb (F)	2.2 cm long, 1.0 cm diameter
	1	Tin Sheet (G)	3.7 diameter, 0.05 cm thick
	2	Electrical Wire (H)	10 cm long, #26 gauge (about 0.05 cm in diameter); strip insulation from 1 cm of each end

2	1.5 Volt Dry Cells (I)	3.2 cm diameter. 5.7 cm long
1	Steel Bolt (J)	2 cm long, 0.5 cm diameter
1	Steel Nut (K)	0.5 cm insid diameter
1	Steel Strapping (L)	12.5 cm x 1.2 cm x 0.05 cm
1	Cardboard (M)	3.5 diameter
1	Cardboard Tube (N)	15 cm long, 3.2 cm inside diameter

b. Construction

(1) Eyepiece

Tube (D)

Cross Section of Tube (D)

If a cardboard tube cannot be found of the required size, one can easily be made from a piece of cardboard cut as shown. Roll the cardboard into a tube (D) 5 cm long and position the single convex lens (B) in place with the edge on the dotted line. The lens can be held in place with rubber cement or similar flexible adhesive while the tube (D) is held together with masking tape. Be certain the flat side of the lens faces the front (notched) end of the tube.

Tube (C)

Cross Section of Tube (C)

Cross Section

The second tube (C) may be made the same way as the first if a manufactured cardboard tube of the correct size cannot be found. Roll the cardboard into a tube and position the double convex lens (A) at one end with rubber cement. Fasten the tube securely with masking tape. This tube (C) should fit rather snugly inside tube (D), but still be able to slide easily back and forth.

(2) Adaptor

Adaptor Pattern

The adaptor can be made from a cardboard tube (E) by notching one end so that it will interlock with the eye-piece. The adaptor and eye-piece can then be taped with masking tape. Alternatively,

the pattern for the adaptor can be cut from cardboard, rolled into a cylinder, and taped. Even if the two tubes don't "mesh" exactly, they can be taped well enough to overcome inaccuracies.

When binding the eyepiece and adaptor together with tape, be sure that the notch in the eyepiece tube (D) is directly over the adaptor tube opening.

(3) Barrel

Tube (N)

If a tube (N) of the correct size is available, simply punch a small hole (0.2 cm) about 6 cm from one end of the tube. Otherwise, a tube can be fashioned from a piece of cardboard of the indicated dimensions. Roll and tape it so that it is 15 cm long and has a 3.2 cm inside diameter.

Cardboard (M)

Side View

To seal off the end of tube (N), use the circular piece of cardboard (M). First, punch a hole in the center of the cardboard disc, and insert the short steel bolt (J). Fasten one of the pieces of electrical wire (H) in place with the nut (K). Pull the free end of the wire through the hole in the tube (N) and glue the disc (M) in place to seal off one end of the tube.

Cross Section of Tube (N)

Reflector (G)

Use the disc of tin sheeting (G) to make a reflector. First, drill a hole in the center of the disc of a diameter such that the pen-light bulb (F) will screw into it securely (approximately 0.7 cm diameter). Next, cut slits in the disc (G) as shown. Fold the resulting flaps up slightly so that

the reflector approximates a cone in appearance.

Next, screw the bulb (F) in place, and solder one end of the second piece of wire (H) to the back of the reflector. Pull the free end of the wire through the hole in the barrel tube (N) and leave the reflector assembly loose temporarily.

Cross Section

Switch (L)

The switch is made from the piece of steel strapping (L). Give it a slight bend in the middle.

Coil the free end of the wire which comes from the sealed end of the barrel. Do likewise for the other wire. Tape the switch to the barrel making certain that one end of the switch is taped directly over one of the wire coils and that the second coil is directly under the bent portion of the switch but not touching it. In

Side Views

other words, when the switch is depressed, contact will be made with the wire coil and the circuit from the bolt to the bulb will be completed.

Finally, insert two dry cells (I) into the barrel and push the reflector assembly into place.

The bulb must make contact with the battery. The reflector assembly should hold in place by tension, and require no further fastening. When the switch is pressed, the light should go on.

Cross Section of Completed Barrel

To complete the illuminated hand magnifier, insert the barrel into the adaptor.

c. Notes

(i) The illuminated hand magnifier must be held directly over the object to be viewed. The light serves to concentrate the illumination of the object while focusing is accomplished by moving the eyepiece tube (C) up and down in relation to the second tube (D).

(ii) This magnifier is excellent for observing detail on such items as insect parts, plant surface features, crystals, etc.

(iii) Obviously, any variation in the lens diameter as given here will necessitate changes in the dimensions of the item. If a lens is slightly smaller than the cylinder into which it must be fit, it can be built up by wrapping thin pieces of tape around its edge until it will fit snugly.

B. MICROSCOPES

B1. Glass Stage Microscope

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Glass Plate	1	Window Glass (A)	20 cm x 10 cm (at least)
(2) Lens Mount	1	Metal Strip (B)	12 cm x 3 cm x 0.1 cm
(3) Mirror	1	Mirror Glass (C)	Approximately 5 cm x 5 cm

b. Construction

(1) Glass Plate

Rest the glass plate (A) on two books or other stable supports. The glass plate serves as the microscope stage.

(2) Lens Mount

Drill a hole through the center of the lens mount (B). The diameter of the hole will depend on the size and type of lens used [see Notes (ii), (iii), (iv)]. Bend the end of the lens mount down at a slight angle.

(3) Mirror

Use the mirror (C) to reflect enough light through the specimen to permit it to be seen well. If a mirror is not available, use polished metal or other reflective material.

c. Notes

(i) Operating the glass stage microscope is exceptionally easy. Simply place the glass slide containing the specimen under the lens mount and reflect light through the specimen with the mirror. Focusing is accomplished by pushing on the lens mount so that the lens moves closer to or further from the specimen.

(ii) For maximum success in making <u>water drop lenses</u>, the hole in the lens mount must be properly prepared. First of all, this means that the hole should be as nearly circular as possible. A drill will yield best results although holes can be punched with nails, punches, or other sharp implements. Additionally, the edge of the hole should be made smooth and free from burrs. This can be done with a file or tool made especially for this purpose. The optimum size for the hole was found to be approximately 2.5 mm - 3.5 mm in diameter.

Once the hole has been made, the area around the hole should be heated and candle wax melted onto both sides of the lens mount around the hole. Be certain that no wax gets into the hole. This coating of wax prevents the

water drop from spreading out and deforming.

When the hole has been prepared, the water drop lens is made simply by carefully placing a drop of water in the middle of the hole so that it is suspended from the edge. The drop is most easily handled with a dropper. It was found that a water drop with a slightly flattened side provided the best image while a drop flattened on both sides was poor.

(iii) The object in making a glass bead lens is to form as nearly spherical and clear a bead as possible. This is most easily done if soft glass rods are available. If harder glass is used, extremely hot flames are needed to work it.

First, evenly heat a portion of the glass rod in a flame until it softens. When it is soft, pull the ends out until a long filament is formed and continue to pull until the filament breaks. Using the longer of the two filaments, heat the tip until a bead begins to form. Turning the filament so that the bead forms evenly, continue to heat the bead until it reaches the desired size. Allow the bead to cool and then break it off along with a portion of the stem.

Beads can be made from approximately 2.0 mm to 5.0 mm in diameter, although those from 2.5 mm - 4.0 mm work best. Before mounting the bead on the lens mount, be certain that the hole in the mount is slightly smaller in

diameter than the bead. This is extremely important. The bead can then be glued or held in place by a rubber band (see diagram).

As the diagrams show, the bead stem should be kept on the underside of the lens mount.

Although glass beads can be made from glass tubing, it is almost impossible to prevent air bubbles from forming in the bead which cause great distortion of the image. Therefore, use solid glass rods, if possible.

(iv) Penlight bulb lenses are made from the penlight bulbs used in small, fountain-pen sized flashlights (battery operated torches). Those commercially available in the United States are approximately 2 cm long and 1 cm in diameter at the widest point. The portion used as a microscope lens is the thickened glass at the tip of the bulb (see diagram).

The lens can be removed from the bulb by scratching the glass portion of the bulb close to the metal part. This avoids scratching the tip of the bulb itself, and is best accomplished with a small, triangular file. Once the whole glass bulb has been separated from the metal part, the lens will break off quite readily; in fact, it may fly off and be damaged unless caution is observed.

The lens may be mounted to the lens mount merely by drilling a hole the same diameter (or slightly smaller) as the lens. Then, apply a flexible glue (e.g., rubber cement) around the edge of the hole and set the lens in place (see diagram). Allow the glue to set before using the microscope.

Cross Section

The penlight bulb lens appears to work best when mounted rounded side up as shown in the diagram.

(v) Because all the microscopes described here are single lens types with small diameter lenses, the focal length is extremely small, which means that the lens must be close to the object viewed and also, the eye must be kept very close to the lens. This tends to cause a strain on the eye if the microscope is to be used for an extended period of time. In addition, it means that the depth of field is extremely limited, requiring frequent adjustments to focus.

(vi) Magnification power for the different lenses is difficult to determine, but it appears that water drops and glass beads of the same diameter have the same power of magnification. Drops or beads with diameters of 2.0 mm to 4.0 mm give magnifications of approximately 40X - 60X to 20X - 30X with smaller diameter beads yielding larger magnifications. The penlight bulb lens is approximately 5 mm in diameter and 3 mm thick, and gives magnification of about 50X - 70X. With all lenses, the portion of the field in focus is rather small.

(vii) Care should be taken to keep the lenses (except water drop) clean with tissues. Also, slides, mirrors, etc., should be kept as dust free as possible.

(viii) The best material for the lens holder seems to be aluminum sheeting about 0.5 mm thick. Other types of stiff, flexible metal sheeting also work well. Cardboard or strong paper can be used, but yields poor results.

(ix) Light to illuminate the specimen should be reflected through the microscope with a mirror or other shiny surface. A strong light source is required with sunlight working as well as any.

B2. Hand-Held Microscope

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Lens Mount	1	Metal Strip (A)	8 cm x 2.5 cm x 0.1 cm
(2) Rubber Band	1	Rubber Band (B)	--

b. Construction

(1) Lens Mount

Drill a hole in the metal strip (A). The position of the hole will depend upon where on the slide the specimen has been mounted.

The dimensions given here are for a lens mount to be used with a standard 7.5 cm x 2.5 cm (3 inches x 1 inch) glass slide.

(2) Rubber Band

Wind the rubber band (B) around the slide and lens mount (A) to hold the two together so they don't slip. Be certain to position the lens directly over the specimen or portion of specimen to be viewed. Take care in moving the lens mount that the edge does not cut the rubber band.

c. Notes

(i) This simple microscope works well with either glass bead or penlight bulb lenses [see I/B1, Notes (iii) and (iv)]. Using it with a water drop lens is quite difficult in that it is difficult to prevent the water from touching the slide. In addition, this microscope works best when held vertically rather than horizontally as is necessary with the water drop.

(ii) See the following diagrams for positioning the glass bead and penlight bulb lenses on the lens mount.

(iii) This microscope should be used primarily with permanently prepared slides as opposed to fresh mounts. Focusing is achieved simply by holding the slide with one hand and moving the lens mount back and forth with the other.

B3. Match Box Microscope *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Match Box Cover (A)	5 cm x 3.5 cm x 1.5 cm
(2) Stage	1	Match Box Drawer (B)	5 cm x 3.5 cm x 1.5 cm
	1	Metal Strip (C)	3 cm x 1 cm x 0.1 cm
(3) Lens Holder	1	Aluminum Strip (D)	7.5 cm x 2.5 cm x 0.1 cm

b. Construction

(1) Body

With a razor blade, make two slits in the back of the match box cover (A). These slits need to be slightly wider than the width of the lens holder (2.5 cm).

*Adapted from African Primary Science Program, Making Things Look Bigger, (Nairobi, Kenya: Curriculum Development and Research Center, 1967), pp 24-25.

(2) Stage

Cut out one end of the match box drawer (B) so that portions of the end 0.5 cm wide are left on either side. At the same end of the drawer, make a slit about 1 cm wide with a razor blade. Insert the metal strip (C) into this slit and glue it in place. Use this strip to move the stage up and down when focusing.

(3) Lens Holder

Drill a hole in one end of the aluminum strip (D), and bend it at right angles. If a drill is not available, punch a hole in the metal with a nail. Insert the metal strip through the slits in the back of the match box cover (A) to insure that it will be held in place securely. Then, remove the lens holder, slide the stage into the body, and replace the lens holder. The microscope is now ready for use.

c. Notes

(i) To use this microscope, place the slide or specimen on the stage directly under the lens. Focusing is accomplished by moving the stage up and down as the lens holder remains stationary. As with all single lens microscopes, the eye must be kept quite close to the lens in order to see the image.

(ii) See I/B1, Notes (ii), (iii), and (iv) for complete instructions in adapting the lens holder to use either water drop, glass bead, or penlight bulb lenses.

(iii) With an item this small, it is found that there is some difficulty in keeping a glass slide on the stage, especially when the stage must be moved in focusing.

(iv) Since it is difficult to get sufficient light through the specimen, it is suggested that the inside of the match box drawer be lined with light colored paper or metal foil to increase reflected light.

(v) This microscope was found to be good for inspecting such items as coins, newsprint, insect wings, crystals, etc.

B4. Adjustable Microscope

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base and Stage Assembly	1	Wood (A)	12 cm x 8 cm x 1.5 cm
	2	Wood (B)	6 cm x 8 cm x 1.5 cm
	1	Nut (C)	0.5 cm internal diameter
(2) Lens Mount Holder	1	Wood (D)	2.5 cm x 8 cm x 1.5 cm
	1	Bolt (E)	0.5 cm diameter, 6 cm long

	1	Wing Nut (F)	0.5 cm internal diameter
	2	Nuts (G)	0.5 cm internal diameter
(3) Lens Mount	1	Wood (H)	10 cm x 3.5 cm x 0.5 cm
	1	Aluminum Sheet (I)	9 cm x 2 cm x 0.1 cm
(4) Adjustment Knob	1	Wood Spool (J)	3 cm long, 2 cm diameter
	1	Bolt (K)	0.5 cm diameter, 6 cm long
	1	Nut (L)	0.5 cm internal diameter
(5) Mirror	1	Mirror Glass (M)	3 cm x 3 cm
	1	Wood (N)	3 cm x 3 cm x 0.5 cm
	1	Metal Sheet (O)	8 cm x 2 cm x 0.05 cm
	1	Nail (P)	5 cm long, 0.2 cm diameter
	1	Tack (Q)	1 cm long

b. Construction

(1) Base and Stage Assembly

Cut a notch 3 cm square in one piece of wood (B) to make the stage. In this same piece, drill a hole through the wood. It should be centered between the edge of the notch and the edge of the stage. Make this hole slightly smaller in diameter than the bolt (K) used to make the adjustment knob. Place the nut (C) over the hole in the wood. Give it a sharp blow with a hammer so that it forms an indentation in the

Stage (B)

Base and Stage Assembly

wood. Remove the nut, then glue it back in place taking care not to get glue in the hole or in the threads of the nut. It is best to allow the nut to dry with the bolt threaded through both it and the hole to assure proper alignment. Nail or screw this piece, the stage (B), to the upright (A). Likewise, nail or screw the base (B) to the upright.

(2) Lens Mount Holder

Cut a notch 0.6 cm deep and 4 cm wide in the piece of wood (D). Drill a hole in the center of the notch. This hole should be slightly smaller than the bolt (E) used to hold the lens mount in place.

Screw the wing nut (F) onto the bolt (E) and run it to the end of the bolt. Use one nut (G) to hold the wing nut tight to the end of the bolt. Place the other nut (G) over the hole in the piece of wood (D) and strike it hard with a hammer, taking care not to split the wood. Remove the

nut from the impression in the wood thus formed, and place a drop of strong glue in the impression and replace the nut. Be sure not to get glue in the threads of the nut or in the hole (this may be avoided by allowing the nut to dry with the bolt run all the way through the hole). Finally, glue, nail or screw the lens mount holder to the base and stage assembly.

(3) Lens Mount

Make a slit in the end of the piece of wood (H), with a saw. This slit should be about 1 cm deep and slightly wider than the thickness of the metal sheet (I) used.

Lens Mount

Bend the aluminum sheet (I) to a right angle 1 cm from its end. Drill a hole 3.5 cm from the bend and centered. The diameter of this hole will depend upon the size of the water drop desired, the size of the glass bead used, or the size of the penlight bulb lens. [See I/B1, Notes (ii), (iii), and (iv) for instruction in making and using such lenses.] Glue the aluminum sheet (I) to the piece of wood (H).

(4) Adjustment Knob

Side View

Run the bolt (K) through the hole in the wooden spool (J). Secure the spool tightly in place with the nut (L). Screw the end of the bolt through the hole and nut in the base and stage assembly.

(5) Mirror

Cut the metal sheet (O) and drill two holes the same diameter as the nail (P) used. Bend the ends up at right angles along the dotted lines. Drill a hole through the wood (N) which is about the same diameter as the nail.

Metal Strip (O)

Completed Mirror

Insert the nail (P) through this hole and glue it in place. Glue the mirror (M) to the wood. Nail or screw the metal strip into position on the base directly under the notch in the stage. Insert both ends of the nail through the holes in the metal strip. There should be enough friction to keep the mirror at the desired angle.

c. Notes

(i) The slide containing the specimen to be observed is placed over the hole in the stage. Light is reflected through the specimen and lens by means of the mirror. Coarse adjustment is obtained by varying the position of the lens mount with the lens mount holder bolt. Fine adjustment is attained by turning the adjustment knob so that it moves the metal portion of the lens mount up and down.

(ii) This microscope may be used with any of the three types of lenses: water drop, glass bead, or penlight bulb lens. See I/B1, Notes (ii), (iii), and (iv) for details in mounting each type lens on the lens mount.

(iii) Light is reflected through the lens by use of the mirror. The mirror need not be a real glass mirror - any smooth, shiny surface (e.g., polished metal) is acceptable. The source of light may be a bulb, room light, or skylight, with skylight proving most satisfactory.

C. SUPPLEMENTARY APPARATUS

C1. Glass Slide and Cover Slip

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Glass Slide	1	Glass Plate (A)	7.5 cm x 2.5 cm x 0.2 cm
(2) Cover Slip	1	Transparent Plastic (B)	2.5 cm x 2.5 cm x 0.05 cm

b. Construction

(1) Glass Slides

Glass slides may be hand cut from plate glass (A), but this is tedious and time consuming.

(2) Cover Slip

Cover slips can be cut from stiff transparent plastic sheets (B) with scissors.

c. Notes

(i) Good quality slides may be purchased almost as inexpensively as they can be handmade, or they may be obtained for free from hospital blood laboratories as they are often discarded after use.

(ii) Consult a good general biology source book for information on preparing either fresh or permanently mounted slides.

C2. Staining Vessel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Tin Can (A)	8 cm high, 8 cm diameter
(2) Rack	1	Wood (B)	8 cm x 2 cm x 2 cm

b. Construction

(1) Can

The diameter of the can (A) may be somewhat larger than 8 cm (it should not be much less), and the height of the can should be about the same as the length of the slides used.

(2) Rack

Cut notches in the wood (B) about 1 cm deep and just slightly wider than the slides used. Paint the wood with a sealant (e.g., varnish, shellac) to prevent the stain from soaking into it. Push the rack down into the

bottom of the can (A), notches up. The rack holds the slides upright and prevents them from touching each other. Always make the length of the rack equal to the diameter of the can to insure that it will fit tightly in the bottom of the can.

c. Notes

(i) Staining vessels are necessary when preparing slides for microscopic inspection. Consult a good standard biology source book for instruction in preparing slides and stains.

C3. Stain Bottle

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bottle	1	Pill Bottle (A)	25-50 ml capacity
(2) Dropper	1	Glass Tube (B)	12 cm long, 0.75 cm diameter
	1	Rubber Tube (C)	4 cm long, 1.0 cm diameter
	1	One-hole Cork Stopper (D)	To fit mouth of pill bottle
	1	Wire (E)	5 cm long

b. Construction

(1) Bottle

Use a clear glass pill or medicine bottle (A).

(2) Dropper

Make the tube portion of the dropper two at a time by heating a piece of glass tubing 20 cm long in the

middle and drawing it out to a narrow filament when soft. Break the tube at the most narrow part of the constriction to form two tubes (B).

Force the glass tube through the one-hole cork stopper (D). Push the piece of rubber tubing (C) onto the wide end of the glass tubing and tie it off with the wire (E) to form the dropper's suction cap. Adjust the length of the glass tube so that when the cork is in place in the bottle, the tip of the glass tube almost touches the bottom of the bottle.

c. Notes

(i) If one-hole cork stoppers are not available, use a cork borer to make them from regular corks or use one-hole rubber stoppers.

(ii) Be sure to label the bottle with the name of the type of stain it contains.

C4. Hand Microtome

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Block and Bolt	1	Wood Block (A)	3 cm x 5 cm x 6 cm
	1	Glass Tubing (B)	5 cm long, 1 cm inside diameter
	1	Wood Dowel (C)	1 cm long, 1 cm diameter
	1	Steel Bolt (D)	9 cm long, approximately 0.7 cm diameter
	1	Nut (E)	To fit bolt

b. Construction

(1) Block and Bolt

End View

Side-View (Cross-section)

End View

Prepare the wood block (A) by drilling or boring a hole slightly larger in diameter than the outside diameter of the glass tubing (B) 4 cm into one end of the block. Drill another hole (0.7 cm diameter) through the same end of the block. This second hole should be

centered in the bottom of the first, larger hole, and be drilled through the block. Next, lay the nut (E) on the end of the block which has the small hole in it. Strike the nut sharply with a hammer to make an impression of the nut in the wood. (Be careful not to split the wood, and also make sure the hole in the nut aligns with the hole in the wood.) After the impression has been made in the wood, glue the nut into place with epoxy resin cement.

Impression of Nut

Side View
(Cross-section)

Shove the piece of glass tubing (B) down into the large hole in the wood (A), and glue it in place. The end of the tube should stick out about 1 cm. See that this end is cut as evenly as possible and fire polish it just enough to remove any possible burrs. Insert the short wooden dowel (C) into the tube. Screw the bolt (D) through the nut until the end of the bolt touches the wooden dowel.

The microtome is now ready for use.

c. Notes

(i) To operate the hand microtome, screw out the bolt until the wood dowel drops to the bottom of the glass tube. Then, insert the section of plant stem (or whatever is to be cut for the microscope slide) into the glass tube. Fill the space which remains between the specimen and the glass tube with melted paraffin and allow it to cool. When the paraffin is hard, screw the bolt in until it begins to force the wood dowel to push the paraffin and specimen out of the glass tube. As the specimen comes out, use a single-edge razor blade to cut off sections. Practice with the microtome will eventually allow very thin sections to be sliced from specimens.

(ii) It may be desirable to substitute metal tubing for the glass as glass is easily broken. Also, painting the end of the wood dowel with shellac or varnish will prevent the paraffin from sticking to it.

II. DISSECTING APPARATUS

A. DISSECTING APPARATUS

These items will permit the student to do many of the dissections normally done in elementary biology course work. If possible, each student should have each of the items in this section, but if cost and materials prohibit this, then enough items should be produced to permit students to work in groups of two or three.

A. DISSECTING APPARATUS

A1. Dissecting Needles

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wood Dowel (A)	10 cm long, 0.6 cm - 0.8 cm diameter
(2) Needle	1	Steel Wire (B)	5 cm long, #20 gauge wire (approximately 0.05 cm diameter)
(3) Binding	1	Iron Wire (C)	About 10 cm of #24 gauge wire (about 0.025 cm diameter)

b. Construction

(1) Handle

The wood dowel (A) serves as the handle. Make a slit about 2 cm deep in one end to receive the needle. Sand the two ends to make them smooth.

(2) Needle

Break the wire (B) by bending it back and forth instead of cutting it with wire cutters as hard steel can easily damage wire cutters. File one end to a point.

At a point 0.3 cm from the unpointed end, grasp the wire with two pliers and slowly bend until a 90° angle has been reached. If a "bent tip" dissecting needle is desired, bend the needle to an angle of 130° approximately 1 cm from the pointed end.

(3) Binding

Insert the end of the needle into the handle about 1 cm deep. Wrap several turns of binding wire (C) tightly around the handle and twist the ends together.

c. Notes

(i) Iron, rather than steel, wire may be used for the needle by first making the bends where needed. Then heat the wire until it becomes dull red and immerse it in cold water to temper it. The iron wire will become hard enough so that it does not bend easily; however, it may be broken if pressed with too much force.

A2. Strapping Scalpel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wood Dowel (A)	10 cm long, 1 cm diameter
(2) Blade	1	Steel Strapping (B)	6 cm long, 1 cm wide
(3) Binding	1	Iron Wire (C)	About 12 cm long, #24 gauge (approximately 0.025 cm diameter)

b. Construction

(1) Handle

Make a slit in one end of the dowel (A) with a saw for the blade. Sand the ends to make them smooth.

(2) Blade

Cut the piece of strapping (B) into the shape of a scalpel blade (many shapes are useful for different purposes). Taper one end so it will fit the handle. File the edges (as shown by the shaded areas) to make the cutting edge.

(3) Binding

Insert the blade into the slit in the end of the handle. Wrap several turns of #24 gauge wire (C) tightly around the handle and twist the ends together. This should hold the blade firmly in place.

c. Notes

(i) The blade should be sharpened after the entire scalpel has been assembled in order to lessen the danger of being cut.

(ii) An equally good scalpel may be made from a piece of strapping about 15 cm long. Simply form a blade at one end as described above, and let the remainder act as the handle. This portion should be wrapped in tape to make it more comfortable to handle.

A3. Razor Scalpel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	2	Steel Strapping (A)	15 cm long, about 1.25 cm wide
	1	Tape (B)	About 50 cm long
(2) Blade	1	Double-Edged Razor Blade (C)	2.5 cm x 3.5 cm
(3) Fasteners	2	Bolts (D)	1.0 cm long, 0.4 cm diameter
	2	Nuts (E)	0.4 cm inside diameter

b. Construction

(1) Handle

Fasten the two pieces of strapping (A) together with tape (B). Drill two holes (0.5 cm diameter) in the other end for the bolts (D) to fit through. Locate these holes so that the razor blade (C) will be held in the desired position.

(2) Blade

Insert the blade between the two halves of the scalpel handle so that the two holes align over the holes in the razor blade.

(3) Fasteners

Insert the short bolts (D) through the holes and screw on the nuts (E). This scalpel is now ready for use.

c. Notes

(i) The razor blade can easily be replaced as it becomes dull.

A4. Scissors

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	2	Steel Strapping (A)	15 cm x 1.25 cm, at least 0.05 cm thick
(2) Fastener	1	Bolt (B)	0.5 cm long, 0.5 cm diameter
	1	Nut (C)	0.5 cm inside diameter

b. Construction

(1) Body

Hold the pieces of strapping (A) tightly together and heat them at a point approximately 6.5 cm from the end until they both glow dull red. Then, twist them a full quarter (90°) turn. Immediately plunge them into

cold water to restore their temper.

Drill a hole 0.6 cm in diameter about 1 cm from the twist on the short (6.5 cm) end of both pieces.

Bend the long (8.5 cm) ends up to form the handles.

Trim the tips of the strapping to the shape of blades. Sharpen the shaded area of the blade. File this area on the <u>outside</u> edge only, not the inside edge where the blades meet. In sharpening, file upward at an angle of 30°.

(2) Fastener

Fasten the two halves of the scissors together with the short bolt (B) (a long bolt may be cut to length) and nut (C). When the proper tightness is obtained, burr the end of the bolt to prevent the nut from loosening and falling off.

c. Notes

(i) Scissors constructed of strapping of 0.05 cm in thickness work fairly well in cutting tissues as long as short cuts are made, and the material being cut is kept well back between the blades.

(ii) Scissors work better if the blades are slightly curved as shown below.

Side View

A5. Forceps

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Strapping	1	Steel Strapping (A)	20 cm long, about 1.25 cm wide

b. Construction

(1) Strapping

Cut each end of the steel strapping (A) to a taper.

Side View

Bend the strapping a full 180° at the midpoint. Make certain the tops touch and are in good alignment. Heat the bent area to dull red and plunge immediately into cold water to temper the steel. Bow the blades of the forceps slightly.

A6. Dropper

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Tube	1	Glass Tubing (A)	7 cm long, about 0.6 cm diameter
(2) Cap	1	Rubber Tubing (B)	4 cm long, 1 cm outside diameter
	2	Soft Wire (C)	4-5 cm long

b. Construction

(1) Tube

Cut

Hold the glass tubing (A) over a hot flame, turning it to heat it evenly. When it begins to soften, draw it out until the constriction is the desired diameter, and allow it to cool. When cool, cut the tubing at the constriction with a small triangular file.

(2) Cap

Slip the rubber tubing (B) over the end of the glass tube. Wrap a piece of wire (C) tightly around the tubing to hold it tight to the glass, and twist the end of the wire together. In a similar manner, close off the open end of the rubber tubing so that it is airtight.

c. Notes

(i) Droppers may be made in many shapes and sizes to fit the various uses for which they are needed.

A7. Dissecting Pan

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pan	1	Oil Can (A)	Approximately 17 cm x 25 cm x 3 cm
(2) Wax	--	Paraffin Wax (B)	Enough to partially fill the pan (about 1 liter)

b. Construction

(1) Pan

Remove the handle from a 4 liter rectangular oil can (A). Cut off the sides about 3 cm from the edge. It is best to put tape on the sharp edges of the pan to prevent students from cutting themselves.

(2) Wax

Fill the pan about two thirds full of melted paraffin wax (B), and allow the wax to harden. Be careful in heating the wax not to get it too hot or it may ignite. It is best to place the paraffin block in a glass jar, and put the glass jar in hot water until the wax melts.

c. Notes

(i) Any container like an oil can (e.g., waxed cardboard milk containers) can be used as long as a suitable pan can be made from it. Alternatively, pans can be made from sheet metal if there is sufficient technical help available.

(ii) Cases for dissecting tools can be made from heavy cloth material if it is desirable to keep each student's kit separate from the others.

III. AQUATIC COLLECTING APPARATUS

These are a wide variety of items used in collecting plant and animal specimens from the aquatic environment. Remember to use waterproof and water resistant materials wherever possible in the construction of this apparatus.

A. NETS AND DREDGES

Nets and dredges are easily made items useful in collecting both plants and animals. They are all made with some sort of netting or mesh.

B. AQUATIC TRAPS

These two traps can be used to catch some types of aquatic animals.

C. SUPPLEMENTARY AQUATIC MATERIALS

Materials included here are less necessary, yet still useful, items in aquatic collection.

A1. Dip Net

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wood Dowel (A)	100 cm long, 2 cm diameter
(2) Loop	1	Heavy Wire (B)	115 cm long, 0.3 cm diameter
	1	Stiff Wire (C)	About 80-90 cm long, 0.1 cm diameter
(3) Net	1	Nylon Bag (D)	50 cm wide, 60 cm long

b. Construction

(1) Handle

The length of the handle may be varied according to personal preference. Cut two grooves in one end of the wood dowel (A), one opposite the other. Make these grooves about 7 cm long, 0.3 cm deep, and about 0.4 cm wide.

(2) Loop

Form a loop 30 cm in diameter from the heavy wire (B). Leave about 7 cm of excess wire at each end which will fit into the grooves in the handle. Bend these 7 cm portions to 90° angles. Fit the wire ends into the grooves in the handle and bind them in place with the stiff wire (C).

Binding of Loop to Handle

(3) Net

If a nylon laundry bag (D) of the given dimensions is used, cut it down so that it is only about 30 cm deep rather than 60. Other types of cloth or netting can also be used. Use cloth or netting through which water can easily pass, but remember that the size of the net weave determines the size of the smallest organisms which will be held by the net. Make sure the opening of the net is 5 - 10 cm greater in circumference than that of the loop. Simply sew the open portion of the net around the loop with strong thread.

c. Notes

(i) The dip net is used to collect aquatic organisms of all kinds from the shore or boat. Be sure to make its construction as sturdy as possible.

A2. Hand Screen

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame and Screen	2	Wood Dowels (A)	45 cm long, 1.5 cm diameter
	1	Stiff Wire (B)	35 cm long, 0.4 cm diameter
	2	Stiff Wire (C)	50 cm long, 0.4 cm diameter
	1	Fine Wire Mesh (D)	35 cm x 50 cm
	1	Fine Wire Mesh (E)	30 cm x 15 cm
	1	Fine Wire (F)	150 cm long, 0.05 cm diameter

b. Construction

(1) Frame and Screen

Front View

Set the two wood dowels (A) so that they are 50 cm apart. Take the wire mesh (D) and secure it to the dowels by wrapping it around each dowel once and then nailing it in place on the dowel. Be sure to leave 10 cm free at one end of each dowel to serve as handles. Drill two holes, 0.4 cm in diameter, in each dowel; drill the first 1 cm from the end with which the wire mesh is even, and the second, 12 cm from the end which is to be the handle.

Detail

Bend the two 50 cm sections of stiff wire (C) into semi-circles, each with a diameter of 30 cm. Place one end of one piece of wire into one hole of the wood dowel, so that about 5 cm of wire is protruding out of each hole. Bend these end pieces around the wood dowel until they reach the main body of wire. Follow this procedure for the other piece of wire. These two pieces of wire now form an outside frame to which the wire mesh (D) is attached.

Detail

Using the fine wire (F), in much the same way as one would use thread in sewing, wire the wire mesh (D) to the stiff wire frame, letting the edges of the wire mesh slightly overlap the wire frame.

Bottom View

Take the last piece of stiff wire (B) and run it between the ends of the two wood dowels with which the wire mesh is flush. Secure it by bending about 3 cm of each end around the wire frame. Now, take the remaining piece of wire mesh (E) and cut it into the shape of a semicircle. Wire this semicircle onto the bottom of the hand screen with the "sewing" method described above.

c. Notes

(i) This simple device is an effective means of collecting small plants and animals in streams. To operate, simply hold it in the water and permit the stream water to flow through the wire mesh and remove organisms as they are collected.

(ii) As an extra measure, have someone stand upstream and disturb rocks, thus chasing out underlying organisms.

A3. Dredge

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Tin Can (A)	15 cm diameter, 18 cm long
(2) Net	1	Nylon Bag (B)	50 cm wide, 60 cm long
	1	Wire Strapping (C)	50 cm long, 1.5 cm wide, 0.05 cm thick
	3	Bolts (D)	1.5 cm long
	3	Nuts (E)	To fit bolts
	2	Cords (F)	20 cm long
	6	Corks (G)	3 cm x 3 cm
	1	Nail (H)	0.5 cm long
(3) Weight	2	Steel Bars (I)	12 cm x 3 cm x 0.3 cm
	2	Bolts (J)	1.5 cm long
	2	Nuts (K)	To fit bolts
	1	Cord (L)	100 cm long

b. Construction

(1) Can

Cut both ends from the tin can (A). Flatten one end of the can to a rough rectangular shape about 15 cm x 10 cm. Drill three holes in the round end of the can, each about 4 cm from the ends. Space these holes every 120° and make them slightly larger in diameter than the bolts (D) used. Make two more holes the same diameter at the other end of the can. These holes should be about 2 cm from the edge and 9 cm apart.

(2) Net

Side View of
Rivet

Make a loop from the strapping (C) that will fit inside the can (i.e., slightly smaller than 15 cm in diameter). To do this easily, drill a small hole near each end of the strapping. Cut the head off a flat-headed nail (H) and insert this nail through the holes in the strapping. Flatten the nail down like a rivet to hold the loop together.

Strapping Loop (C)

Drill holes in the strapping which will align with the holes in the round end of the can. One might wish to drill these holes before riveting the loop together. These holes should be the same diameter as the holes in the can.

Side View

Sew the open end of the nylon bag (B) around the strapping loop with stout thread. The net may also be made from nylon netting if ready-made bags are unavailable. Punch holes through the nylon bag to correspond to the holes in the strapping loop. Fasten the net and loop to the can with the three nuts (E) and bolts (D).

Detail of Cork (G) Attachment

Punch holes through the six corks (G) and tie one of them to each of the two cords (F). Run each of the cords through two of the remaining corks and tie one cord to each corner of the net (B). It may be necessary to sew around each connection to prevent the nylon from tearing.

(3) Weight

Drill two holes slightly larger than the bolts (J) used in each steel bar (I). Make these holes 9 cm apart so they will align with the holes already drilled in the can. Insert the two bolts (J) through the holes in one of the steel bars and then put the bolts through the holes in the can so that the steel bar weight is on the outside of the can. Stretch the cord (L) around the two bolts.

Place the second steel bar (I) over the two bolts and fasten with the nuts (K). The cord (L) should be firmly held between the can and bar. Tie the loose end of the cord together to form a loop.

c. Notes

(i) In use, the dredge is tied to a long rope and dragged along the bottom of a body of water. Organisms living on or near the bottom are collected in the net.

(ii) The weights insure that the dredge will stay in the correct position on the bottom. The corks are to help keep the net off the bottom until it is

filled with collected material. This prevents it from being torn.

(iii) Use water resistant materials wherever possible in construction of this and all aquatic apparatus.

A4. Plankton Net *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Net	1	Nylon or Silk Stocking (A)	About 50 cm long
	1	Metal Strapping (B)	40 cm long, 1.5 cm wide, 0.05 cm thick, 2.5 cm diameter
(2) Bottle	1	Glass Bottle (C)	2.5 cm diameter, 6 cm long
	1	Rubber Band (D)	--
(3) Tow Line	2	Cords (E)	60 cm long
	1	Lead Weight (F)	Weight is variable

b. Construction

(1) Net

Drill four holes into the metal strapping (A) at 13 cm intervals. Make the holes about 0.3 cm in diameter.

*Adapted from Biological Sciences Curriculum Study, High School Biology: Student's Manual, (Chicago: Rand McNally and Company, 1963), p 157.

Hold the strapping in a ring shape and sew the open end of the stocking (A) to this ring. Cut off the foot of the stocking.

(2) Bottle

Attach the glass bottle (C) to the end of the net by wrapping the rubber band (D) tightly around it. Be sure the opening to the bottle is not clogged by material from the net.

(3) Tow Line

Punch small holes in the net to correspond to the three holes in the strapping ring. Tie one end of one cord (E) to one of these holes, make a loop in the middle of the cord, and tie the other end to the hole formed where the two ends of the strapping overlap. Next, tie the other cord (E) to the remaining hole in the ring. Tie the middle of this cord to the knot in the other cord, and tie the free end to a lead fishing weight (F).

c. Notes

(i) The plankton net is best used by dragging it behind a boat near the surface of the water. Organisms are trapped in the bottle as the water washes through the net.

(ii) Use netting with as fine a mesh as possible. An old parachute is an excellent source of material for the net.

A5. Two-Man Seine*

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Nylon Rope (A)	250 cm long, 0.5 cm diameter
	3	Cork Floats (B)	15 cm long, 10 cm diameter
	2	Wood Dowels (C)	150 cm long, 3 cm diameter
	1	Galvanized Chain (D)	200 cm long
(2) Mesh	1	Nylon Cord (E)	About 1000 cm long, 0.2 cm diameter
	1	Nylon Seine Net (F)	130 cm x 200 cm

b. Construction

(1) Frame

Fasten the ends of the chain (D) to the bottoms of the wooden dowels (C). Tie one end of the nylon rope (A) to the top of one dowel about 20 cm from the end. Run the free end of the rope through the holes in the cork floats (B) and tie it to the other

*Adapted from Jens W. Knudsen, Biological Techniques, (New York: Harper and Row, 1966), p 326.

dowel so that the distance between the two dowels when the rope is stretched out is 200 cm.

(2) Mesh

Use a mesh (F) from 0.25 to 0.50 cm square. Fasten it to the dowel (C), chain (D), and rope (A) as shown by using the small diameter nylon cord (E).

Attachment of Mesh (F) to Rope (A)

Attachment of Mesh (F) to Dowel (C)

Attachment of Mesh (F) to Chain (D)

c. Notes

(i) Two persons are required to use the seine net. Each holds one of the poles upright in the water and they both walk slowly toward the shore. A great variety of organisms can be collected in this manner.

(ii) Wherever possible, use corrosion and rot resistant materials for the seine such as nylon rope, cord and mesh and galvanized chain.

A6. Lift Net *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Net	1	Nylon Mesh (A)	50 cm x 50 cm
	4	Metal Washers (B)	1.5 cm diameter
(2) Spreaders	2	Heavy Wires (C)	100 cm long, 0.3 cm diameter

b. Construction

(1) Net

Corner Detail

Construction of the lift net is quite simple. Simply fold over each corner of the nylon mesh (A) and sew a washer (B) to the double thickness of material. Punch a hole through the center of each washer and through the double layer of nylon.

*Adapted from Jens W. Knudsen, Biological Techniques, (New York: Harper and Row, 1966), p 283.

(2) Spreaders

Roll each wire (C) to a roughly semicircular shape. Insert one end of each wire through adjacent corners of the net and bend up the ends. Insert the other end of each wire through the corner diagonally opposite the first corner and bend up the ends again. Use a small piece of wire to bind the spreaders together where they cross.

c. Notes

(i) Use the lift net to catch small fish and crustaceans. Place a suitable bait firmly tied to a weight in the center of the net. Tie a line to the lift net where the spreaders cross and lower the net into the water. If the water is clear, watch for fish or crustaceans to near the center of the net, and when they do, quickly lift the net to trap them. If the water is not clear, simply wait for one or two minute intervals before quickly raising the net.

(ii) Small fish may be collected by floating food on the surface of the water. As small fish come to the food, the net may be raised, and the fish collected.

B. AQUATIC TRAPS

B1. Piling Trap

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Suspended Traps	1	Wood (A)	24 cm x 24 cm x 4 cm

4	Wood (B)	10 cm x 10 cm x 2 cm
1	Wire (C)	120 cm long, 0.1 cm diameter
1	Metal Rod (D)	26 cm long, 1.5 cm diameter
5	Nails (E)	2.5 cm long, 0.3 cm diameter

b. Construction

(1) Suspended Traps

Place a heavy staple or bent nail (E) in the center of the large block of wood (A). Drill a hole 0.4 cm in diameter through the center of each of the small blocks of wood (B). Place a nail (E) near each of the holes and wrap the wire (C) around these nails as it is passed through the holes. Bend the nails down across the holes. The small blocks should be spaced about 20 cm apart, with the first block about 30 cm from the large wood block (A), and the metal rod (D) about 30 cm from the last block. Drill a hole in the metal rod through which the wire is run, and connect the rod to the wire. Finally, attach the upper end of the wire to the staple or bent nail on the underside of the large block of wood.

c. Notes

(i) Many aquatic animals attach themselves to the bottom of boats and piers. This trap utilizes this principle in capturing these organisms. To operate, simply place the apparatus in the water and remove approximately every 30 days and collect the organisms which have attached themselves to the blocks of wood.

(ii) The large wood block may be substituted for by some other type of float. A watertight plastic container (e.g., an empty plastic bottle of bleach) can be used. This float can be painted a bright color, thus making it easy to see.

(iii) Any type of weight may be used provided that it is not heavy enough to submerge the large block of wood while still keeping the small blocks of wood under water.

B2. Funnel Trap

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Wire Mesh (A)	45 cm x 80 cm
	1	Wire Mesh (B)	25 cm diameter
	1	Stiff Wire (C)	85 cm long, 0.2 cm diameter
	1	Stiff Wire (D)	50 cm long, 0.2 cm diameter
	1	Fine Wire (E)	0.05 cm diameter, about 300 cm long
(2) Funnel	1	Stiff Wire (F)	85 cm long, 0.2 cm diameter
	1	Spring (G)	2 cm long
	1	Wire Mesh (H)	30 cm diameter
	4	Wire Mesh (I)	17 cm x 17 cm
	1	Fine Wire (J)	0.05 cm diameter, about 300 cm long

b. Construction

(1) Body

Make a cylinder 45 cm long and 25 cm in diameter from the rectangular piece of wire mesh (A). Wire the 45 cm sides together with the fine

wire (E) in much the same way as one would sew a cloth seam. Let the edges of the mesh overlap about 1 cm to facilitate "sewing" them together with the wire.

Next, bend the stiff wire (D) to the shape of a "U". Make two small holes 10 cm apart in the cylinder. Insert the U-shaped wire through these two holes, and bend up the ends leaving about 2.5 cm of the wire extending out of the cylinder as a handle. Take the 25 cm diameter piece of wire mesh (B) and "sew" it to one end of the cylinder with a piece of fine wire (E) to seal it off.

Finally, make a 25 cm diameter "hoop" from the stiff wire (C) by hooking the ends together. Connect the wire hoop to the open end of the cylinder with fine wire to stiffen the cylinder. This is best done by folding about 2 cm of the end of the cylinder back over the hoop and sewing the hoop inside this flap for the full circumference of the hoop.

(2) Funnel

Cut a square 17 cm on a side from the center of the circular piece of wire mesh (H). Also, cut a V-shaped notch 2.5 cm deep in one edge of the piece of mesh.

Cut the four pieces of wire mesh (I) into triangular-shaped pieces 17 cm at the base and 5 cm at the apex. Sew the four pieces together along their long edges with fine wire (J) to form a pyramid-shaped funnel.

Mesh Funnel

Sew the funnel to the circular piece of mesh (H) with the square cutout.

Form a hoop from the stiff wire (F) 25 cm in diameter with small loops at both ends. Connect these two ends of the hoop with the spring (G). (Springs can easily be made by wrapping stiff wire around a pencil or other round object.)

Now, fold up a ridge 2.5 cm high all around the circumference of the circular piece of mesh (H). Wire the hoop (F) to this ridge making certain the spring (G) on the hoop aligns with the "V" notch in the mesh. Fit this funnel assembly over the end of the cylindrical body by pulling the spring open slightly. Slip the funnel over the end of the cylinder and let the spring snap back. The tension of the spring should hold the funnel assembly to the cylinder relatively tightly.

c. Notes

(i) Use of the funnel trap is simple. Just remove the funnel portion of the trap by spreading open the spring slightly and pulling the funnel off the cylinder. Place some rocks or other weights in the trap to hold it down in the water, and place a suitable bait (e.g., pieces of fish, old cheese wrapped in

a cloth bag) in the cylinder. Replace the funnel, and tie a length of rope to the handle. Drop the trap into a stream or pond, and tie the other end of the rope to an object on the bank or a float (a plastic bottle makes an excellent float). Check the trap periodically to remove captured animals and replace baits.

(ii) The following two patterns can also be used for the funnel:

The first pattern is used because it wastes less material while the second is good because only one seam needs to be sewn while the others are merely folded.

(iii) Wherever possible, use rustproof materials like aluminum screening in the construction of this item.

(iv) The circular and other shapes can more easily be cut from the wire mesh if a pattern is first cut from paper and taped to the mesh. Then cut around the paper rather than attempting to draw a pattern on the mesh as this is extremely difficult to do.

C. SUPPLEMENTARY AQUATIC MATERIALS

C1. Bottom Sampler

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Tin Can (A)	12 cm long, 8 cm diameter
	1	Hinge (B)	--
	3	Bolts (C)	1.0 cm long
	2	Nuts (D)	To fit bolts
	3	Wood Screws (E)	1.0 cm long
(2) Handle	1	Wood (F)	5 cm x 4 cm x 4 cm
	1	Wood Dowel (G)	2.5 cm diameter, length variable
	1	Eyed Screw (H)	--
	1	Wire (I)	18 cm long

b. Construction

(1) Can

Top View

Remove one end of the tin can (A). Punch a small hole near the bottom of the can. At the open end of the can fasten one plate of the hinge (B) to the can with the bolts (C) and nuts (D). Holes will have to be drilled or punched through the can for the bolts to go through. The hinge may be fastened to the can with sheet metal screws if these are available.

(2) Handle

Side View

Drill or bore a hole the same diameter as the wood dowel (G) through the middle of the wood block (F). Insert one end of the dowel into the block and screw or glue them together. With screws (E), fasten the plate of the hinge (B) to the bottom of the block. Screw the eyed screw (H) into the other side of the wood block. Finally, make a knot in the end of the wire (I) and pass the free end through the hole in the bottom of the can (the knot must be inside the can) and tie the free end to the eyed screw.

Bottom View

c. Notes

(i) To operate, simply lower the sampler into the water until the can hits bottom. Drag the can back and forth until it feels heavy, then pull it out of the water and remove the bottom sediment. The wire prevents the can from hitting bottom with the open end pushed against the handle so that no sediment can enter it. Collect bottom samples in different ponds and streams to check the sediment for the various organisms living in each.

(ii) The length of the handle will vary according to the depth of the water where the sample is to be taken.

(iii) The details of design of this item depend mainly on the type of hinge used.

C2. Grappling Hook

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Prongs	6	Stiff Wire (A)	40 cm long, 0.25 cm diameter
	1	Soft Wire (B)	About 100 cm long, 0.05 cm diameter
(2) Sheath	1	Sheet Metal (C)	12 cm x 8 cm x 0.05 cm
	2	Soft Wire (D)	8 cm long, 0.1 cm diameter

b. Construction

(1) Prongs

Bend each piece of stiff wire (A) to the shape of a hook with a loop at one end. Group the prongs together by twos and bind them together

with the soft wire (B).

Then place the three resulting double prongs together and bind them so that the prongs are about at angles of 120° to each other.

(2) Sheath

To finish the grappling hook simply wrap the piece of metal sheet (C) around the middle of the hook and bind it in place with the soft wire (D).

c. Notes

(i) To use the hook, just tie it to the end of a rope or cord, drop it into the water, and pull it up when it becomes entangled in vegetation.

(ii) Be careful when handling this item of the sharp edges of the sheet metal and the points of the wire used in binding it together.

(iii) If heavy steel wire is available, only one piece is needed per hook rather than two.

C3. Grappling Bar

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	25 cm x 4 cm x 2 cm
	24	Nails (B)	5 cm long, 0.2 cm diameter
(2) Handle	1	Soft Wire (C)	50 cm long, 0.2 cm diameter
	2	Nails (D)	3 cm long
(3) Weight	2	Lead Pipe (E)	8 cm long, 1.5 cm diameter

b. Construction

(1) Body

Drive the nails (B) through the wood (A) in two rows, staggering them so that they don't align directly above one another. One row of nails is nailed through from one side while the other row is

nailed through the opposite side.

Side Views

Where the nails have been driven through the wood, bend them upwards at approximately 45° angles as close to the base as possible.

(2) Handle

Hammer one of the nails (D) into the end of the body and let it protrude about 1 cm. Twist one end of the soft wire (C) around the nail, then hammer it down completely.

(3) Weight

Slip the two pieces of lead pipe (E) over the free end of the handle, and fasten the free end to the opposite end of the body. Bend the handle at its middle allowing one weight to slide down each arm of the handle.

<u>c. Notes</u>

(i) To use the grappling bar, tie the end of a long, stout rope or cord to the handle. Drop the bar in water, allow it to reach bottom, and drag it along until resistance is felt, then haul it up The bar works well for retrieving plant specimens from pond and river bottoms.

(ii) Be certain the weights are sufficient to sink the bar easily, as wood can be extremely buoyant.

C4. Water Glass

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Glass	1	Glass Plate (A)	6.3 cm x 10.3 cm x 0.3 cm
(2) Frame	4	Wood (B)	20 cm x 9 cm x 2 cm

b. Construction

(1) Glass Plate

Cut the piece of glass (A) to the specified dimensions, making sure that all the edges are smooth and free of burrs.

(2) Frame

Cut a groove, 0.3 cm wide and 0.7 cm deep, across the width of each piece of wood (B), 1.2 cm from one end. Fasten two of the pieces of wood together at right angles using waterproof cement along the point of contact. Be sure that the grooves are lined up and that they face to the inside. Use nails or screws to reinforce this joint. Glue two sides of the glass plate with waterproof cement into the two grooves, placing the long side of the glass plate into the groove in the piece of wood with a width of 9 cm. The next piece of wood should be placed so that the groove holds the larger of the two free sides remaining on the glass plate. The last piece of wood then fits over the final free end. These last two pieces of wood should be glued and nailed to the previously assembled structure

as they are put into place. Seal the ends of the grooves on the outside of the water glass with waterproof cement. Make certain all seams are waterproof.

c. Notes

(i) The water glass is designed to view the bottom organisms of a body of water. When the end with the glass plate is inserted into the water, glare from the sun as well as surface ripples are eliminated.

IV. TERRESTRIAL COLLECTING APPARATUS

These items are designed for use in collecting land invertebrates, vertebrates, and plants. Instructions for killing, preserving, and storing these organisms can be found in a variety of books and journals.

A. INSECT COLLECTING APPARATUS

Insects are the most common, familiar organisms everywhere in the world. Items described in this section are used in collecting and treating them.

B. SOIL ORGANISM COLLECTING APPARATUS

These pieces of equipment enable students to discover the multitude and diversity of living things in the soil.

C. SMALL VERTEBRATE COLLECTING APPARATUS

Small lizards, snakes, birds and mammals may be captured alive using these devices.

D. PLANT COLLECTING APPARATUS

The vasculum and plant presses in this section are used in collecting and preserving plant materials.

A. INSECT COLLECTING APPARATUS

A1. Butterfly Net

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wood Dowel (A)	100 cm long, 2 cm diameter
(2) Loop	1	Heavy Wire (B)	115 cm long, 0.3 cm diameter
	1	Stiff Wire (C)	About 80-90 cm long, 0.1 cm diameter
(3) Net	1	Nylon Bag (D)	50 cm wide, 60 cm long

b. Construction

(1) Handle

The length of the dowel (A) from which the handle is made may be varied according to personal preference. Cut two grooves in one end of the handle, one opposite the other. Make these grooves about 7 cm long, 0.3 cm deep, and about 0.4 cm wide.

(2) Loop

Form a loop 30 cm in diameter from the heavy wire (B). Leave about 7 cm of excess wire at each end which will fit into the grooves in the handle. Bend these 7 cm portions to 90° angles. Fit the wire ends into the grooves in the handle and bind them in place with the stiff wire (C).

Binding of Loop to Handle

(3) Net

Select a finely meshed nylon laundry bag (D) or sew a net from a piece of nylon cloth or similar sturdy cloth with a relatively open weave. Whether a bag is used or a net sewn specifically for the butterfly net, make sure the opening of the net is 5 - 10 cm greater in circumference than that of the loop. Simply sew the open portion of the net around the loop with strong thread.

c. Notes

(i) Use the butterfly net to collect flying insects of all kinds. If it is sturdily made, it can also be swept through high grass to collect insects living in the grass. Consult a good source book for information on preserving, mounting, and storing collected insects.

(ii) The material used for the net must have a fine mesh through which insects cannot escape. At the same time, the mesh must be open enough to permit air to easily pass through it with little resistance. Parachute nylon is especially good for this purpose.

A2. Killing Jars

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Stopper	1	Stopper (A)	To fit bottle
(2) Bottle	1	Glass Pill Bottle (B)	Approximately 10 cm long, 4 cm diameter

b. Construction

(1) Stopper — Select a cork or rubber stopper (A) which will effectively seal the bottle airtight.

(2) Bottle — Use a glass bottle (B) with a wide mouth.

c. Notes

(i) Killing bottles for insects can be made in several ways. Some are exceptionally dangerous and should only be used by the instructor. Be certain to label all jars as to their contents.

(ii) The following are methods of preparing killing jars:

(A) Cyanide Killing Jar - This is extremely dangerous and should only be used by the instructor. First, put a thin layer (0.5 cm) of potassium or sodium cyanide crystals in the bottom of the bottle. Cover this with a similar layer of fine sawdust or dry plaster of Paris. Finally, cover both layers with a layer of wet plaster of Paris. The jar is ready to use when the plaster hardens. Be sure to keep it tightly stoppered except to kill insects. Use only rubber stoppers.

(B) Ethyl Acetate Killing Jar - Put a thin (0.5 cm) layer of wet plaster of Paris in the bottom of the jar. When it has dried, put some ethyl acetate over the plaster and cover it with a small amount of tissue paper. This is also

especially dangerous and should be kept tightly stoppered.

(C) Carbon Tetrachloride Killing Jar (1) - Pin a small piece of blotting paper or cotton to the bottom of the stopper. Saturate this with carbon tetrachloride just before putting the insects in the jar. This is a much safer jar for student use as the carbon tetrachloride quickly evaporates.

(D) Carbon Tetrachloride Killing Jar (2) - Use a one-hole stopper for the jar with a short piece of glass tubing extending through the hole. Plug one end of the tube with cotton. Place the insect in the jar, and replace the stopper. Then, carbon tetrachloride can be dripped through the tube onto the cotton plug where the fumes will kill the insect.

(E) Carbon Tetrachloride Killing Jar (3) - Place several rubber bands in the bottom of the jar and soak them overnight in carbon tetrachloride. Pour off the excess liquid and put a tight-fitting piece of blotting paper over the bands to keep them in place. This jar is relatively long lasting in its killing power.

(iii) The cork or rubber stoppers may absorb the toxic fumes from the jar so be sure to destroy them when the jars are discarded. Be absolutely certain that no fumes escape through the cork. It may be necessary to dip cork stoppers in melted paraffin wax to seal them completely.

A3. Relaxing Jar

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Stopper	1	Cork Stopper (A)	To fit bottle
(2) Bottle	1	Glass Pill Bottle (B)	Approximately 10 cm long, 4 cm diameter

b. Construction

(1) Stopper — Select a cork or rubber stopper (A) which will effectively seal the bottle airtight.

(2) Bottle — Use a glass bottle (B) with a wide mouth.

c. Notes

(i) Relaxing bottles are used to make dead insects more flexible so that they can be manipulated into a desirable mounting position.

(ii) The following is a method for preparing a relaxing jar: Place some moist sand in the bottom of the jar and add a few drops of carbolic acid to inhibit mold growth. Cover the sand with a piece of moist blotter paper. Leave the insects in the jar overnight to relax them.

A4. Insect Spreading Board

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Platform	1	Wood (A)	12 cm x 30 cm x 1.0 cm
	2	Wood (B)	5.5 cm x 30 cm x 0.5 cm
	2	Wood (C)	5.5 cm x 1 cm x 2 cm

b. Construction

(1) Platform

Cut the two small pieces of wood (C) in half diagonally, yielding four wedge-shaped pieces. Glue two of the wedges to the backs of each of the two slats (B). Turn the two slats over and glue them to the base (A). Leave a 1.0 cm gap between the two slats.

c. Notes

(i) Make the slats (B) from the softest wood available (e.g., balsa). Consult a good biological source book for details on preparing insects to be pinned and prepared on the spreading board.

(ii) A simple, inexpensive spreading board can be made from a cardboard box. Remove the top and cut the ends as shown in the illustration. Then glue two pieces of cardboard to the box to complete the spreading board.

A5. Beating Sheet *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Sheet and Supports	1	Heavy Cloth (A)	100 cm x 100 cm
	2	Wooden Slats (B)	125 cm x 4 cm x 1.0 cm

b. Construction

(1) Sheet and Supports

Fold back about 10 cm of the heavy cloth (A) (muslin will work) at each corner and sew a pocket into each such that the tips of the wooden slats (B) will fit into them.

*Adapted from Jens W. Knudsen, Biological Techniques, (New York: Harper and Row, 1966), p 209.

c. Notes

(i) The sheet is held under shrubbery and insects are shaken off onto it where they can easily be captured.

(ii) Bamboo, wooden dowels, broom handles, etc. can be substituted for the wooden slats. In any case, the crosspieces can be removed after use to permit compact storage.

A6. Aspirator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Receptacle	1	Test Tube (A)	15 cm long, 1.6 cm inside diameter
	1	2-Hole Stopper (B)	To fit test tube
(2) Draw Tube	1	Glass Tube (C)	6 cm long, 0.2 cm inside diameter
	1	Rubber Tube (D)	35 cm long, 0.3 cm inside diameter
	1	Gauze (E)	1 cm x 2 cm
	1	Tape (F)	2 cm long
(3) Intake Tube	1	Glass Tubing (G)	16 cm long, 0.3 cm inside diameter

b. Construction

(1) Receptacle

Plug the end of the test tube (A) with a two-hole stopper (B).

(2) Draw Tube

Use the tape (F) to hold the gauze (E) in place over the end of the glass tube (C). Be certain air still flows freely through the end of the tube. Insert the end of the tube through one of the holes in the stopper. Attach the end of the rubber tube (D) to the glass tube (C).

(3) Intake Tube

Bend the glass tube (G) to an 120° angle about 6 cm from one end, and insert this end into the remaining hole in the stopper.

c. Notes

(i) The aspirator is a useful instrument when collecting insects which are too small or too fragile to be collected by hand. To operate, place the draw tube between one's teeth and the intake tube near the insect to be collected. The collector then sucks in and the insect is captured. The gauze prevents the insect from entering the draw tube.

(ii) A glass bottle or vial may be used in place of a test tube, but in any case a tight-fitting stopper is required. The stopper may be either rubber or cork, and cotton may be used in place of the gauze.

A7. Night Flying Insect Collector

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	20 cm x 20 cm x 2 cm
	1	Electric Lightbulb Socket (Porcelain) (B)	12 cm diameter
	2	Electrical Wire (C)	50 cm long, 0.3 cm diameter
	1	Electrical Plug (D)	--
(2) Body	2	Wood (E)	22 cm x 50 cm x 1.0 cm
	2	Wood (F)	20 cm x 50 cm x 1.0 cm
	1	Hinge (G)	--
	4	Fine Wire Mesh (H)	20 cm x 17 cm
	1	Thick Rubber Band (I)	--
	1	Glass Container with Lip (J)	500 ml
	1	Light Bulb (K)	100 watts
	2	Screw Eyes (L)	2.5 cm long, 0.2 cm diameter
	1	Wire (M)	60 cm long, 0.1 cm diameter

1	Thin Sheet Metal (N)	10 cm x 10 cm
1	Wire (O)	10 cm long, 0.1 cm diameter
2	Wood Screws (P)	1 cm long

b. Construction

(1) Base

The electric light bulb socket (B) is centered on the base (A) and two holes are drilled through the base for the attachment of the electrical wires (C) to the terminals on the electric light socket. Attach the electrical wires to these terminals and extend them through the base. The socket is then screwed into place on the base using wood screws. Attach the electrical plug (D) to the wires to complete the base.

(2) Body

The two pieces of wood (F) are nailed into place on opposite sides of the base. One of the pieces of wood (E) is nailed onto the third side of the base where it overlaps the two ends of the sides already attached. It is then nailed to the other two sides. Take the last piece of wood (E) and attach the hinge (G) to the bottom of it and to the bottom of the base so that it forms a door which opens downward.

Side View

Pattern

Completed Funnel

Take the four pieces of wire mesh (H) and cut them to the pattern shown, then wire them together along their edges to form a square funnel. The opening at the bottom of the funnel (4 cm square) should be the same width as the diameter of the neck of the collecting bottle (J) used. Nail three of the edges of the funnel along the top edges of the fixed sides of the trap. Of course, do not nail the fourth edge to the door or the door will not open.

Collar

Next, cut a collar from the piece of sheet metal (N) so that it will fit under the lip on the glass container (J). Cut this collar in such a way so that it

Side View

Top View

does not form a continuous circle, but instead has a break in it. Now, wrap the collar tightly around the neck of the glass container just under the lip. Pull the two free ends together and overlap them. Then punch a hole through the ends and place the piece of wire (O) through the holes and bend it so that it holds the collar tightly closed. The glass container can now be picked up by the collar without falling through it. Remove the collar, force the mouth of the glass container up through the bottom of the hole in the funnel, and replace the collar so that it holds the glass container in place.

Place two screws (P), one on the outside of the door about 2 cm down from the top, and the other in the same position on the side opposite the door. Then, close the door and stretch the rubber band (I) from one screw to the other over the top to hold the door closed. Finally, attach the two screw eyes (L) to opposite corners on the sides of the top and secure the wire (M) to them, and screw the light bulb (K) into the socket.

c. Notes

(i) To operate, simply hang the trap at night outside from a fixture (e.g., a tree limb), and attach the electrical wires to a power supply. Be sure to hang it in an area where there are a large number of night-flying insects. The light will attract the insects and they will fall into the glass container. When a sufficient number have become trapped in the container, place a wad of cotton soaked in carbon tetrachloride over the opening, thus killing the insects.

(ii) By placing two hinges on the side of the door, it can be opened to the side if so desired.

B. SOIL ORGANISM COLLECTING APPARATUS

B1. Soil Organism Sieve

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Sieve	2	Wood (A)	30 cm x 10 cm x 2 cm
	2	Wood (B)	26 cm x 10 cm x 2 cm
	1	Wire Screen (C)	30 cm x 30 cm

b. Construction

(1) Sieve

Frame

Simply nail or screw the four wood boards (A,B) together to form a frame and nail the piece of screen (C) to the bottom of the frame.

c. Notes

(i) Use the sieve to separate out soil organisms such as worms, grubs, etc., from the material in which they are living.

(ii) Carefully choose the size of wire mesh used in the sieve. A mesh or screen with too fine a weave will become clogged with soil and rendered useless. A relatively wide mesh will work well if the soil is coarse, allowing the organisms to fall through the mesh while holding back the soil.

(iii) A frame for the sieve can also be made by knocking out the bottom from an old drawer or wooden box.

B2. Soil Insect Trap

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Tin Can (A)	0.5 liter capacity
(2) Funnel	1	Wire Mesh (B)	About 15 cm x 15 cm

b. Construction

(1) Can

Remove one end from a tin can (A).

(2) Funnel

Cut a pattern for the funnel from the wire mesh (B). The outside diameter of the pattern should be approximately 2 cm wider than the diameter of the can (A) used.

Connect the two edges of the cutout portion of the pattern by "sewing" them together with wire. This will result in a cone with a hole at the apex. Complete the soil insect trap

Side View

by inserting the funnel in the open end of the can and folding the excess wire mesh down around the outside of the can to hold it in place. If necessary, a piece of wire wrapped around the outside of the can and twisted tightly will help hold the funnel in place too.

c. Notes

(i) Place the trap in a hole in the ground so that the top edge of the trap is even with the soil level. Thus, small insects and other ground organisms crawling across the trap will fall through the hole in the funnel into the can. Check the can periodically for captured organisms.

(ii) The trap can be varied by making the funnel portion from aluminum foil, waxed paper, or other materials which are smooth and will help prevent the organisms from crawling out of the trap. Also, dusting the inside walls of the can with fine powder (e.g., talcum powder) will prevent organisms from crawling up the walls and out of the cage.

B3. Baermann Funnel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Funnel	1	Glass Bottle (A)	About 7 cm diameter, 20 cm long
	1	Glass Tube (B)	5 cm long, 0.5 cm inside diameter
	1	1-Hole Stopper (C)	To fit bottle opening
	1	Rubber Tube (D)	12 cm long
(2) Screen	1	Fine Wire Mesh (E)	7 cm diameter
	1	Stiff Wire (F)	16 cm long, 0.3 cm diameter
(3) Clamp	1	Screw Clamp (G)	CHEM/IV/A4

b. Construction

(1) Funnel

Soda Pop Bottle

Cut the top of a glass soda pop bottle (A) off (See CHEM/I/F2). Force a short piece of glass tubing (B) through the one-hole stopper (C) and seal the opening with the stopper. Next, attach the rubber tube (D) to the glass tube.

(2) Screen

Ring

Make a ring slightly smaller in diameter (i.e., about 5 cm diameter) than the bottle with the stiff wire (F). Fold the edge of the circular piece of wire mesh (E) under the wire ring. The wire mesh will probably be stiff enough to hold itself in place without being wired to the ring.

(3) Clamp

Use the clamp (G) to seal the rubber tube airtight.

c. Notes

(i) The Baermann funnel is designed to extract soil nematodes from soil. To use it, it must be supported by a ring stand. Clamp off the tubing, and let the end of the tube extend into a small vial or bottle. Set the wire mesh disc into the funnel, put a small cloth bag of soil on the disc, and fill the apparatus with water. After an hour or so, release the clamp to collect a small sample of water which can be examined for soil nematodes. (See illustration on next page.)

(ii) If commercial funnels of the correct size are available and inexpensive, they can be substituted for the bottle funnel. Also, the end of the rubber tube can be sealed off with a pencil stub or piece of wooden dowel if a good clamp is not available.

B4. Berlese Funnel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Funnel	1	Glass Bottle (A)	About 7 cm diameter, 20 cm long
(2) Steel Wool	1	Steel Wool (B)	30 g
(3) Glass Jar	1	Glass Jar (C)	50 ml capacity

b. Construction

(1) Funnel

Cut the top of a soda pop bottle (A) off (See CHEM/I/F2) to make the funnel. Alternately, use a commercial glass or metal funnel, or make one using metal foil or heavy paper.

(2) Steel Wool

Place the steel wool (B) inside the funnel so that it blocks off the opening.

(3) Glass Jar

Fill the jar (C) about 1/2 full of alcohol or formalin and place it directly under the funnel.

c. Notes

(i) To use the Berlese funnel, a ring stand and light source are needed. Support the funnel with the ring stand so that the neck of the funnel is directly over the glass jar. Place a 25 watt light directly above the funnel and close enough to the funnel that the heat from the bulb will warm the contents of the funnel. Place the soil sample in the funnel so that it rests on the steel wool. Pick out the larger soil organisms with forceps. The smaller organisms will be driven down by the light and heat of the bulb until they drop through the steel wool into the preservative in the jar. The apparatus should be left in place several days to insure that most of the organisms are collected.

C. SMALL VERTEBRATE COLLECTING APPARATUS

C1. Simple Box Trap

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	3	Wood (A)	60 cm x 20 cm x 1.0 cm
	1	Wood (B)	58 cm x 20 cm x 1.0 cm
	2	Wood (C)	5 cm x 5 cm x 0.5 cm
	1	Wire Mesh (D)	20 cm x 22 cm
(2) Trip	1	Wood (E)	17.5 cm x 55 cm x 0.5 cm
	1	Metal Hinge (F)	5 cm x 5 cm
	1	Eyed Screw (G)	2 cm long
	1	String (H)	85 cm
	1	Wood (I)	10 cm x 4 cm x 1.5 cm
	4	Round-headed Screws (J)	Approximately 1.0 cm long
(3) Door	1	Construction Board (K)	19 cm x 20.5 cm x 0.25 cm
	1	Flat Metal (L)	15 cm x 1.5 cm x 0.5 cm

	2	Bolts (M)	1.25 cm long
	2	Nuts (N)	To fit bolts
(4) Stop	4	Tacks (O)	1.0 cm long
	1	String (P)	7 cm
	1	Rubber Band (Q)	--
	1	Wood (R)	6 cm x 2 cm x 2 cm
	1	Bolt (S)	5 cm long
	1	Nut (T)	To fit bolt

b. Construction

(1) Body

Begin the body by cutting a goove 0.3 cm wide and 0.5 cm deep parallel to the end of two of the pieces of wood (A). This groove is 1.0 cm from the end. Nail or screw these two boards to the third board (A).

Top View

In the corner of the board (B) to be used as the top, drill a hole 0.7 cm in diameter about 3 cm from each edge, and drill a hole about 0.5 cm in diameter through the other end of the top, 1.0 cm from the edge and centered. Set this board (B) aside until the trip (2) is completed.

Seal off one end of the body by nailing the wire mesh (D) to it. Reinforce the corners with triangular pieces of wood gotten by cutting the wood pieces (C) in half diagonally. Again, do not seal the end until the trip (2) and top board (B) are in place.

(2) Trip

Screw the eyed screw (G) into one end of the wood (E) about 1.0 cm from the edge and centered. To the back of this board, fasten the hinge (F) which also should be about 1.0 cm from the edge and centered. Next, fasten the other half of the hinge to the bottom of the body so that the board is centered in the bottom of the body (i.e., it should be 2.5 cm from each end and 0.25 cm from each side of the body). Use round-headed screws (J) so that the hinge cannot close completely flat. In this way, the trip will be held up at a slight angle, which is needed in the design of this trap. Alternately, the length and tension of the trip string (N) can be adjusted to hold the trip in

the desired position without the necessity of using this type of hinge and screws.

Now tie one end of the string to the eyed screw (G) in the trip (H). Run the other end of the string through the hole in the top board (B) of the body which may now be nailed or screwed into place. Also, the wire mesh (D) for the end of the body may be fastened in place after the top is finished.

Side View (Cross-section)

To complete the trip, cut a notch from the block of wood (I) and attach the free end of the string to the block by tying it through a hole drilled in the block.

Side View (Cross-section)

(3) Door

Detail

Cut a hole 4.25 x 1.0 cm in the construction board (K) 3 cm from the end of the board and centered. Next, using the nuts (N) and the bolts (M), bolt the flat metal bar (L) into position just under the hole. Holes will have to be drilled through the board for the bolt to go through. The door is now finished and should slide easily up and down in the notches in the sides of the body.

(4) Stop

Cut the piece of wood (R) as shown and drill a hole in the wood slightly larger in diameter than the bolt (S) used.

Hammer a tack (O) into each side of the stop (R), and run a bolt (S) through the stop and the hole in the corner of the top. Screw the nut (T) loosely onto the bolt. Hammer two other tacks (O) into the top of the body, one to either side of the stop and slightly behind it. Finally, tie the piece of string (P) between the tack in the left side of the stop and the tack to the left in the top, and similarly attach the rubber band (Q) on the right side. Fix the tension in the rubber band so that the stop will be held out over the door when the door is closed, thus preventing the door from being raised after the trap has been sprung.

c. Notes

(i) To set the trap up, place it where small animals are likely to be found. Push the stop out of the way and put the door between the grooves in a raised position. Next, push the notched portion of the trip block through the hole in the door to hold the door up. Release the stop, allowing the rubber band to pull it against the door. At this point, the string attaching the trip block to the trip should be taut. Finally, place a suitable bait in the extreme rear of the cage on the trip.

Side View
(Cross-section)

Trap in "Set" Position

Because the round heads of the hinge screws hold the trip up at a slight angle, the animal entering the trap must move to the rear of the trap before the combination of its (the animal's) weight and leverage causes the rear of the trip to drop down, pulling the trip block back out of the hole in the door. The door then drops down in the grooves, the metal bar aiding in a faster drop. Finally, the stop is pulled out over the top of the door once the door is out of its way, and is held over the door because the rubber band pulls against the string.

(ii) It may be desirable to modify the construction of this trap by making it with wire mesh sides as many animals are difficult to entice into enclosed spaces.

(iii) This design can be altered in many ways, especially with respect to proportion, dimensions, and materials used, including plywood or other thin but strong construction materials.

C2. Potter Bird Trap *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Wood (A)	24 cm x 2 cm x 2 cm
	4	Wood (B)	50 cm x 2 cm x 2 cm
	7	Wood (C)	20 cm x 2 cm x 2 cm
	4	Wire Screen (D)	23 cm x 49 cm
	1	Wire Screen (E)	23 cm x 23 cm
(2) Door	1	Stiff Wire (F)	125 cm long, 0.3 cm diameter
	1	Stiff Wire (G)	60 cm long, 0.3 cm diameter
	4	Stiff Wire (H)	27 cm long, 0.3 cm diameter
	1	Wire Screen (I)	22 cm x 22 cm
(3) Trip	1	"U" Tack (J)	1 cm long
	1	Stiff Wire (K)	25 cm long, 0.3 cm diameter

*Adapted from Nuffield Foundation, Teacher's Guide III: The Maintenance of Life, (England: Longmans/Penguin Books, 1966), p 201.

3	"U" Tacks (L)	1 cm long
1	Wood (M)	19 cm x 12 cm x 1.0 cm

b. Construction

(1) Frame

Nail and glue the basic framework together as shown. Begin by nailing one piece of wood (C) to the ends of two long pieces (B). Nail four of the remaining short pieces (C) to the U-shaped piece already made. Nail one in an upright position at each end of each long piece (B) to form the corners of the trap. Next, nail the two remaining pieces of both the short (C) and long (D) wood to the ends of the four upright pieces to complete the basic trap framework.

Drill holes the same diameter (0.3 cm) as the stiff wire (F) used for the door in the piece of wood (A) to act as "seats" for the door frame. Drill these holes 1.5 cm deep. Nail the four long pieces of screen (D) to the sides, bottom and top of the trap and nail the square piece (E) to the rear end to enclose all but the front of the trap in screening.

(2) Door

Bend the ends of two pieces of wire (H) over about 2 cm from each end. Bend the ends of the other two pieces (H) around the first two pieces to form a square framework. Fold two edges of the wire screen (I) around two sides of the frame

Front View

and "sew" the screen together with wire.

Bend the piece of wire (F) to a "U" shape. Slip the ends of this wire through the open ends of the wires in the door frame. The door should slide up and down easily with the U-shaped wire acting as a guide. Next, imbed the ends of the "U" into the holes in the front piece (A) of the wooden frame. They may be glued in place if necessary. When the door slides down the guide, it should effectively block the entrance of the trap with little or no gap.

Side View

Tack the end of the piece of wire (G) to the rear of the cage with a "U" tack (J) and bend it down until it touches the top of the door frame. Bend the remaining end around the wire (F) to help stabilize and support the door frame.

(3) Trip

Bend up 5 cm of the wire (K) to a right (90°) angle and bend 1.0 cm of the other end of the wire to a right angle in the opposite direction. Tack the wire to the wood (M) with the three "U" tacks (L) as near to one of the 12 cm edges as possible.

c. Notes

(i) To use the Potter bird trap, place it in a place where the desired type of bird is known to congregate. It may be necessary to anchor the trap in some manner in order to prevent it from being disturbed. The trap is set by pulling the sliding door all the way up and placing the trip inside the trap at such an angle that, when the door is lowered, the lower cross wire of the door rests on the bent portion of the trip wire. The slight pressure of the door on the trip should both hold the door up (and open) and keep the trip at a slight angle. Finally, bait the trap with a suitable attractant for the particular type of birds desired. A bird entering the trap for the bait will hop on the wooden part of the trip causing the wire to be pulled out from under the door which will drop down in place and trap the bird.

(ii) This trap, unlike others, doesn't require the hunter to hide in a blind waiting for a bird to enter.

(iii) The dimensions of this trap can be altered according to the size of the birds being trapped. Also, the trap may be baited in such a way as to attract other animals besides birds.

C3. Snare

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wooden Rod (A)	100 cm long, 2 cm diameter
	2	Eyed Screws (B)	1 cm diameter opening
(2) Cord	1	Insulated Copper Wire (C)	250 cm long, 0.3 cm diameter
	1	Washer (D)	3 cm diameter
	1	"U" Tack (E)	1 cm long

b. Construction

(1) Handle

Screw one eyed screw (B) 15 cm from the end of the wooden rod (A) and screw the second screw (B) 50 cm from the other end.

(2) Cord

Tie the cord (C) securely to the rod at a point approximately 10 - 15 cm from the end. The short end should be at least 10 cm long as it will be used again to be tied to the long end.

Run the long end of the cord up to the end of the rod and form a loop. Hold the loop in place with a U-shaped tack (E).

At the end of the loop, begin wrapping the long end of the cord tightly around the rod until the short end has been reached. At that point, tie the long and short ends securely.

Extend the long end through the loop and then extend it back to form the snare. The long end is kept in position by extending the ends through the eyes on the rod. When the long end of the cord extends through the second eyed screw, tie the large metal washer (D) to it to make a pull ring.

c. Notes

(i) Use the snare to capture snakes, lizards, and other small animals which are difficult or dangerous to capture by hand. The loop must be placed over the animal's head, then pulled tight to hold it fast.

(ii) Bamboo or other materials may be used instead of wood for the rod. Rope can be used instead of insulated wire, but the wire is better since it is stiff and this helps keep the snare loop open instead of hanging limp.

C4. Reptile Hook

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wooden Dowel (A)	100 cm long, 1.5 cm diameter
	1	Nail (B)	1.5 cm long, about 0.2 cm diameter
	2	Eyed Screws (C)	2 cm long, 1 cm diameter opening
(2) Fixed Jaws	2	Sheet Metal (D)	10 cm x 6 cm x 0.1 cm
	2	Tape (E)	About 50 cm
(3) Movable Jaw	1	Sheet Metal (F)	10 cm x 9 cm x 0.1 cm
	1	Spring (G)	12 cm x 0.5 cm
	1	Steel Wire (H)	100 cm long
	1	Washer (I)	3 cm diameter
	1	Bolt (J)	0.4 cm diameter, 2.5 cm long
	1	Wing Nut (K)	0.4 cm internal diameter
	1	Tape (L)	About 50 cm
	1	Rubber Tubing (M)	7 cm long, 1.0 cm diameter

b. Construction

(1) Handle

Screw the two eyed screws (C) into the wooden dowel (A) so that the opening of the "eye" faces the ends of the dowel. Hammer the nail (B) into the opposite side of the dowel at the angle indicated.

Cut a notch into the end of the dowel nearest the nail. This notch needs to be 3 cm deep and about 0.15 cm wide (i.e., slightly wider than the sheet metal (F) used for the movable jaw). Finally, drill a hole 0.4 cm in diameter 1 cm from the end, and perpendicular to the notch.

(2) Fixed Jaws

Cut the two fixed jaws to shape from the sheet metal (D). Drill or punch a hole 0.5 cm in diameter through the wide portion of each jaw, centered, and 0.3 cm from the flat edge. Cut a slit into each jaw about 0.7 cm long and in approximately the position indicated. Bend the resulting point of metal in on one jaw and out on the other (i.e., in opposite directions). To complete the jaws, cover at least the inner edge with tape (E), cloth, etc., to protect the animals being collected from cuts.

(3) Movable Jaw

The movable jaw, made from sheet metal (F), is identical in shape to the fixed jaws except that one arm is extended for 4 cm. Three holes must be drilled or punched in the jaw. The two lower holes need to be 0.5 cm in diameter while the third need only be about 0.2 cm in diameter. Pad the inner edge of the movable jaw by slitting one

side of a 7 cm long piece of rubber tubing (M), and slipping it over the edge of the jaw. Use tape (L) to hold the tubing in place. Alternatively, the jaw may simply be padded with cloth and tape or other materials.

Top View

Attach the jaws to the handle in this order: Run the bolt (J) through one fixed jaw, halfway through the handle, through the middle hole of the movable jaw, through the rest of the handle and through the second fixed jaw. Screw on the wing nut (K) to secure the whole assembly. Be certain that the "bent points" of the fixed jaws both point in, rather than out. Fix tension on the wing nut such that the jaws are not loose, but the movable jaw still can be freely moved. The "bent points" of the fixed jaws prevent them from rotating backwards about the bolt.

Side View

Next, attach the steel wire (H) to the upper hole of the movable jaw and run the free end through both eyed screws (C). Fasten the free end to the washer (I). Fasten one end of the spring (G) to the remaining hole in the

movable jaw, stretch out the spring, and fasten the free end to the nail (B). The movable jaw should be held wide open, and the reptile hook is ready for use. [Note: If a spring of the correct size and tension is not available, one can easily be made by winding steel wire (about 0.08 cm diameter) around a pencil or other cylindrical rod.]

c. Notes

(i) Other materials such as bamboo, broom handles, etc., may be used for the handle. Also, a strong rubber band may be substituted for the spring.

(ii) If the sheet metal used for the jaws is sufficiently stiff and strong, only one fixed jaw may be required instead of two.

D. PLANT COLLECTING APPARATUS

D1. Vasculum

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Tin Can (A)	4 liter capacity (about 18 cm long by 15 cm diameter) or larger
	1	Rope (B)	50 cm x 0.5 cm
(2) Top	1	Tin Sheet (C)	15 cm diameter, 0.05 cm thick
(3) Door	1	Tin Sheet (D)	14 cm x 8 cm x 0.05 cm
	1	Wood Dowel (E)	2.5 cm long, 2.5 cm diameter
	1	Nail (F)	3 cm long, 0.3 cm diameter

b. Construction

(1) Body

Use a hacksaw to make two slits in the side of the can (A). Each slit is 6.5 cm wide. The first slit is 5.5 cm from the bottom of the can, and the second slit is 7.0 cm from the first. Also, around the top edge (the top being the end which has been removed) make a series of slits approximately 2 cm deep and 2 cm apart.

Remove Shaded Portion

After these initial slits have been made, remove part of the can between the two slits leaving about 1.5 cm of metal to either side of the opening. Further, bend down all of the flaps made in the top edge of the can except for three, specifically those three which are 90°, 180°, and 270° from a point directly above the door.

Detail of Door Guides

To make the guides for the door, first bend the 1.5 cm flaps out until they touch the can, then double them over so that the door will slide between them without falling out. This second step is best done by holding the door in place and bending the flaps over it.

Finally, drill or punch two holes (about 1 cm diameter) in

one side of the can. Pass an end of the rope (B) through each hole and knot the ends inside the can so that the rope cannot pull out.

(2) Top

Merely cut out a circular piece of tin sheet (C) the same size as the end of the can. Place this piece on top of the bent down flaps and bend down the remaining three flaps. The top should slide in and out easily.

(3) Door

Roll the sheet metal (D) slightly until the slight curvature conforms to the side of the can. Make two slits 2 cm deep and 2 cm wide in one end, and bend the flap down. Make the door handle from the dowel (E) and nail (F). Simply drive the nail through the end of the dowel and through the door itself. Flatten the point of the nail like a rivet to hold the handle in place. When finished, the door should slide easily between the guides on the side of the can. The flap on the end of the door serves to help hold down the top as well as preventing the top from sliding out by accident.

c. Notes

(i) The vasculum is used to keep plant materials from excessively drying out when collecting in the field. Put the plants in the vasculum through the door when collecting, and remove them by removing the top.

(ii) If large tin cans with replacable lids are available, these will do nicely and will eliminate the need for cutting out the door and lid. Also, see VII/A2 (Sterilizer) for an alternate method of making the lid for a tin can of this type.

D2(1). Plant Press (Field Type)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Plates	2	Wood (or Plywood) (A)	25 cm x 20 cm x 1.0 cm
(2) Rubber Straps	2	Heavy Rubber Bands (B)	2.5 cm wide, 15 cm diameter

b. Construction

(1) Plates

Cut the wood (A) to size. Smaller or larger sizes may be made according to personal preference.

(2) Rubber Straps

Cut the rubber straps (B) from old automobile tire inner tubes.

Section of Inner Tube

c. Notes

(i) Use the field plant press to hold plant materials until they can be returned to the laboratory. Place the plants between several layers of newspaper, and place the newspapers between the press plates. Wrap the rubber straps around the plates and newspapers to hold them securely until they are returned to the laboratory.

(ii) Lengths of rope or belt-like straps can be used to tighten the press rather than the rubber straps.

D2(2). Plant Press (Laboratory Type)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Lower Plate	1	Plywood (A)	25 cm x 20 cm x 1.25 cm
	2	Bolts (B)	15 cm long, 0.7 cm diameter
(2) Upper Plate	1	Plywood (C)	25 cm x 20 cm x 1.25 cm
	2	Wood (D)	15 cm x 1.75 cm x 1.75 cm
(3) Tightening Handles	2	Nuts (E)	0.7 cm inside diameter
	2	Wood (F)	15 cm x 1.75 cm x 1.75 cm
	2	Washers (G)	1 cm inside diameter, 2 cm outside diameter

b. Construction

(1) Lower Plate

Drill a hole through each end of the plywood (A) (regular wood may be used as well) 2 cm from the end and centered. The holes should be 0.8 cm in diameter. Pass the bolts (B) through these holes as far as they will go.

(2) Upper Plate

Top View

Side View

Nail or glue the two wood strips (D) to the plywood (C) 1.2 cm from the ends and parallel to the edge. Drill a hole 0.8 cm in diameter through the wood strip and plywood at each end. Put the upper plate into position by running the two bolts (B) in the lower plate through the holes in it (the upper plate).

(3) Tightening Handles

Side View

Drill a hole 0.8 cm in diameter through the center of each strip of wood (F). Then, place a nut (E) directly over the hole in the wood and give it a sharp rap with a hammer. Remove the nut from the depression thus formed, put some epoxy resin cement in the depression and glue the nut in place in the depression. When the glue has hardened, place a washer (G) over each bolt, and screw on the tightening handles. The laboratory plant press is now ready for use.

c. Notes

(i) To use the laboratory plant press, place collected specimens between several layers of newspaper and tighten the two plates of the press together very tightly. Leave the plants in the press until they are thoroughly dried out.

V. AQUARIA AND TERRARIA

A. CLASSROOM DEMONSTRATION AQUARIA

This is the most common type of aquarium and is used for student observation of the various relationships demonstrated by an ecosystem. Therefore, this type of aquarium is characterized by the use of glass.

B. BREEDING AQUARIUM

This is used to provide places for maintaining and growing a supply of aquatic organisms. Since the purpose is not primarily that of student observation, glass sides are not necessary.

C. TEMPORARY AQUARIUM

This is useful for short-term storage of fish and aquatic plants. Depending on the materials used, the temporary aquarium will suffice to hold plants and animals for approximately one to seven days, or much longer if care is taken in its construction.

D. TERRARIA

Any container in which plants can be grown will serve as a terrarium. The chief criterion for such a structure is that it be large enough to give the desired plants room to grow without crowding.

A. CLASSROOM DEMONSTRATION AQUARIA

A1. Quickly Made Demonstration Aquarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jar	1	Glass Jar (A)	2 liters or larger

b. Construction

(1) Jar

Simply clean out the jar (A), add water and fish. Sand and small plants may also be added.

c. Notes

(i) The number and size of fish which can be kept in a non-aerated aquarium varies, but a general rule is at least 2 liters of water per each centimeter of fish. Remember that the amount of oxygen available to the fish depends on the surface area of the water so that jars with narrow necks should be filled only to the point where the neck begins to narrow.

(ii) This or any aquarium may be covered to prevent fish from jumping out, but remember to allow some air flow under the cover to insure that oxygen will dissolve from the air into the water.

A2. Jug or Carboy Aquarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jug	1	Glass Jug or Carboy (A)	3-4 liters or larger

b. Construction

(1) Jug

Remove the top portion of a jug or carboy (A) by either method described under item CHEM/I/F2.

c. Notes

(i) When the neck is removed, add water, sand, plants and fish. Remember, at least 2 liters of water is required for each centimeter of fish.

B. BREEDING AQUARIUM

B1. Breeding Aquarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Drum	1	Oil Drum (A)	100 liters or larger

b. Construction

(1) Drum

Remove the top from a large oil drum (A) or any similar container. Clean the drum thoroughly before adding water, plants, sand and fish.

c. Notes

(i) Since many fish breed best or only when plants are present in the aquarium, a light source may have to be placed over the top of the drum to provide for healthy plants.

(ii) Most fish are extremely sensitive to water containing a high concentration of metallic ions, so the drum should be lined with a plastic bag, or the inside painted with non-leaded paint or other non-toxic coating.

C. TEMPORARY AQUARIUM

C1. Plastic Bag Aquarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Rectangular Tin Can (A)	4 liter capacity or larger (at least 10 cm x 15 cm x 25 cm)
(2) Plastic Bag	1	Plastic Bag (or Sheeting) (B)	50 cm x 60 cm
(3) Tape	2	Masking Tape (C)	30 cm
	2	Masking Tape (D)	20 cm

b. Construction

(1) Can

Cut the top and one side out of a four liter rectangular tin can (A) leaving about 1.5 cm of metal remaining to provide rigidity. Such cans can easily be cut with metal snips or shears. Begin each hole by

Top View

holding the can firmly, placing the edge of a screwdriver against the side, and striking the screwdriver sharply with a hammer. The sharp edges of the metal should be taped to prevent them from cutting the plastic.

Side View

(2) Plastic Bag

Use a large clear plastic bag or piece of plastic sheeting (B). Carefully place the middle of the plastic on the bottom of the inside of the can (A) and spread the plastic out so it fills up the inside. Let the excess plastic extend above the can. Next, carefully pour water into the center of the plastic until the can is filled to the level desired.

(3) Tape

Use the four pieces of masking tape (C,D) that hold down the excess plastic sheeting. Waterproof plastic tape is recommended instead of masking tape if it is available.

c. Notes

(i) With this design, fish and other aquatic organisms can be easily viewed while the three sides of the can provide excellent rigidity. Gravel, plants, rocks, etc., may be placed in the aquarium to provide a more natural environment.

D. TERRARIA

D1. Simple Terrarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jar	1	Glass Jar (A)	4 liters or larger
(2) Cover	1	Plastic Sheeting (B)	Approximately 12 cm diameter
	1	Adhesive Tape (C)	40 cm long
(3) Stand	1	Cardboard Box (D)	15 cm x 15 cm x 10 cm

b. Construction

(1) Jar

Select a wide-mouthed glass jar (A), the larger the jar and the wider the mouth, the better.

(2) Cover

Tape a circular piece of plastic sheeting (B) over the mouth of the jar with the tape (C) to make it fairly airtight.

(3) Stand

Cut two semicircular pieces from the cardboard box (D) so the terrarium can be set on it without rolling off.

c. Notes

(i) Fill the bottom of the terrarium with rich soil and add plants or seeds. The plastic cover will prevent moisture loss and permit some gas exchange. The jar lid may be used instead, but it has a tendency to rust.

(ii) More durable stands made from metal or wood may be constructed if desired.

D2. Glass Terrarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Tin Can (A)	32 cm x 22 cm x 5 cm
(2) Plaster of Paris	--	Plaster of Paris (B)	--
(3) Sides	2	Glass Plates (C)	30 cm x 20 cm x 0.3 cm
	2	Glass Plates (D)	20 cm x 20 cm x 0.3 cm
	1	Plastic Sheet (E)	35 cm x 25 cm
	4	Tape (F)	--

b. Construction

(1) Base

Cut the base from a rectangular tin can (A) to the approximate dimensions given. Adequate bases can also be made from wood, cardboard, sheet metal, etc.

(2) Plaster of Paris

Mix about 1 liter of dry plaster of Paris (B) with enough water to make it workable but stiff.

(3) Sides

Spread the plaster of Paris (B) thickly around the sides of the base (A). Set the plates of glass (C,D) in the plaster while it is wet. Tape the corners where the glass plates come together with tape (F) to hold the sides upright while the plaster is drying. Cover the terrarium with the plastic sheet (E) when plants are kept in it to prevent moisture loss.

Partial Cross-Section

c. Notes

(i) The dimensions of this terrarium may be varied in order to meet special needs or to fit materials available.

(ii) Plants may be placed in the terrarium in pots or planted in soil. If they are planted in soil, be certain that the plaster used is impervious to water.

D3. Plant Growth Chamber

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	25 cm x 25 cm x 2 cm
	2	Wood (B)	27 cm x 5 cm x 1.0 cm
	2	Wood (C)	25 cm x 5 cm x 1.0 cm
(2) Frame	2	Soft Wire (D)	75 cm long, 0.2 cm diameter
	2	Soft Wire (E)	25 cm long, 0.2 cm diameter
	4	Wire (F)	10 cm long, 0.1 cm diameter
(3) Plastic Cover	5	Transparent Plastic Sheeting (G)	30 cm x 30 cm
	--	Tape (H)	--

b. Construction

(1) Base

Nail or glue the four rectangular pieces of wood (B,C) to the square piece (A). Drill four holes, 0.2 cm diameter, in the square piece (A), one hole near each corner of the wood.

(2) Frame

Bend the two longest pieces of soft wire (D) into a "U" shape, and insert the ends into the holes in the base. Fasten the shorter pieces of soft wire (E) to the frame by bending about 1 cm of each end around the bends in the longer wires (D). Bind the joints together with the short, thinner wires (F).

(3) Plastic Cover

Cut a piece of transparent plastic sheeting (G) to the pattern shown or use five separate pieces of sheeting. Whether using the single or separate sheets, cover the frame with plastic and seal the joints between the sheeting with tape (H). Leave one side of the sheeting loose to be used as a "door" in order to easily remove the plants.

c. Notes

(i) Plants may be placed in the chamber in pots or soil may be placed in the base in order to hold the plants.

(ii) Dimensions for the plant growth chamber may be altered in any way depending upon the purposes to which it will be put. Especially, the base needs to have more depth than 3 cm if plants are to be grown in soil rather than pots.

VI. CAGES

A. GLASS CAGES

These cages, made wholly or largely of glass, can be used to house a large variety of small animals, from insects to small mammals.

B. WOODEN CAGES

Two wooden cages are offered, one to house insects and the other designed for small mammals or birds. Both are somewhat more elaborate and permanent than their equivalent glass cages.

C. TEMPERATURE CONTROLLED CAGES

The vivarium and egg incubator are heated with light bulbs to serve the needs of animals and eggs which require relatively higher temperatures to live or hatch, respectively. Use a thermostat to control the internal temperature of heated cages and incubators, especially in classrooms which are not themselves thermostatically temperature controlled.

A. GLASS CAGES

A1. Glass Jar Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jar	1	Glass Jar (A)	4 liters capacity or larger
(2) Top	1	Glass Jar Top (B)	To fit jar
	1	Wire Screening (C)	Same diameter as jar top

b. Construction

(1) Jar

Thoroughly clean the large glass jar (A). Select one with as large a mouth as possible.

(2) Top

Cut out a circular piece from the metal top (B) of the glass jar. The diameter of the hole in the top should be about 1 cm less than that of the top itself.

Next, cut out a circular piece of wire screen (C) the same diameter as the top. Insert this wire screen inside the top and glue it in place if it does not stay in place by itself.

c. Notes

(i) If the wire screening is cut to a diameter very slightly larger than that of the metal top, it will tend to stay in place within the top, and doesn't need to be cemented. In fact, once the top is screwed to the jar, the screen will be held tightly between the glass and top, and no cement is necessary.

(ii) Grass, sand, soil, twigs, etc., can be added to this cage depending on what type of animal is to be kept. If small amphibians are housed in it, lay it on its side and partially fill it with water. Most amphibians are best housed in shallow aquaria, however.

A2. Jar Cage Shelf *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Plywood (A)	18 cm x 47 cm x 1.0 cm
	2	Plywood (B)	18 cm x 15 cm x 1.0 cm
	2	Wood (C)	4 cm x 47 cm x 1.0 cm
(2) Rests	1	Wood (D)	4 cm x 45 cm x 1.0 cm
	1	Wood (E)	2 cm x 47 cm x 1.0 cm

b. Construction

(1) Frame

Back View

Nail or screw the two small pieces of plywood (B) to the ends of the large piece (A). Nail one of the wood strips (C) to the back with the lower edge even with the back. Screw the other strip (C) to the top to act as a carrying handle.

*Adapted from Richard E. Barthelemy, et. al., Innovations in Equipment and Techniques for the Biology Teaching Laboratory, (Boston: D. C. Heath, 1964), p 28.

(2) Rests

Wood Strip (D)

Wood Strip (E)

Wooden rests are needed to prevent the jar cages from rolling. Cut four arcs spaced 10 cm on center from the wide piece of wood (D). The diameter of the arcs should be the same as that of the body of the jar cages (in this description, the jars used had a body diameter of 7 cm and a neck diameter of 6 cm).

Side View
(Cross-section)

Similarly, cut four arcs of the same diameter as the neck of the bottle (in this case, 6 cm) from the narrow strip (E), also 10 cm on center. Nail the wide strip (D) to the sides and base about 3 cm from the back strip. Nail the narrow strip (E) to the front with its lower edge even with the base.

c. Notes

(i) Use this item as a storage rack for several jar cages (VI/A1). The handle permits several cages to be carried with little disturbance.

(ii) All dimensions given here are subject to change depending on the size, shape, and number of jar cages to be stored.

A3. Cockroach Cage *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cage	1	Glass Jar Cage (VI/A1) (A)	At least 1.0 liter capacity
(2) Food Container	1	Jar Top (B)	2-3 cm diameter, 1 cm deep
(3) Watering Device	1	Glass Vial (C)	4 cm long, 2 cm diameter
	1	Cotton (D)	Small plug

b. Construction

(1) Cage	Use the Glass Jar Cage (VI/A1) (A) as is.
(2) Food Container	A small jar top (B) will hold the small amount of food necessary for small insects like cockroaches.
(3) Watering Device	Insert the cotton plug (D) into the open end of the vial (C) containing a small amount of water. The cotton will stay

*Adapted from Richard E. Barthelemy, et. al., Innovations in Equipment and Techniques for the Biology Teaching Laboratory, (Boston: D. C. Heath, 1964), p 22-23.

damp and provide water for the insects.

c. Notes

(i) If desired, the upper portion of the jar can be coated with talcum powder to prevent the insects from crawling out when the jar is open.

(ii) Providing small objects which the insects can climb on or conceal themselves in is recommended.

A4. Housefly Cage *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cage	1	Glass Jar Cage (VI/A1) (A)	4 liters or larger
(2) Watering Device	1	Glass Jar (B)	Approximately 25 ml
	1	Absorbent Paper (C)	Approximately 10 cm x 3 cm
(3) Food Container	1	Jar Top (D)	4 cm long, 2 cm diameter
(4) Culture Medium	1	Culture Medium (E)	50 ml or enough to fill the cage to a depth of approximately 2 cm

b. Construction

(1) Cage

Use the Glass Jar Cage (VI/A1) (A) as is. Be sure to select a glass jar with as wide a mouth as possible.

(2) Water Device

This is merely a small glass jar (B) or other small container which holds a "wick" of absorbent paper (C). Water in the jar will soak into the paper

*Adapted from Richard E. Barthelemy, et. al., Innovations in Equipment and Techniques in the Biology Teaching Laboratory, (Boston: D. C. Heath, 1964), p 23.

where it can be obtained by flies and other flying insects.

(3) Food Container

A small jar top (D) will suffice as a container for food for the flies.

(4) Culture Medium

This is a growth medium (E) for the insect larvae, and should contain all the necessary growth ingredients.

c. Notes

(i) For suitable growth media for houseflies, see the following BSCS publications: Barthelemy et. al., Innovations in Equipment and Techniques for the Biology Teaching Laboratory; and Glenn, The Complementarity of Structure and Function (BSCS Laboratory Block).

A5. Cylinder Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cylinder Cage	1	Potted Plant (A)	--
	1	Lamp Chimney (B)	8 cm diameter, 30 cm long
	1	Cloth Mesh (C)	10 cm diameter
	1	Rubber Band (D)	--

b. Construction

(1) Cylinder Cage

This is a quickly made cage. Simply put the lamp chimney (B) or other large diameter glass tube over the potted plant (A). Add the insects, and cover the top with cloth mesh (C) or gauze held in place with the rubber band (D).

c. Notes

(i) This is a good, simple cage in which to rear insects which feed on plants.

A6. Jar Wormery

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jar	1	Glass Jar (A)	1-4 liters
(2) Medium	1	Sand (B)	1/4-1 liter
	1	Leaf Mold (C)	1/4-1 liter
	1	Loam (D)	1/4-1 liter

b. Construction

(1) Jar — Thoroughly clean the glass jar (A).

(2) Medium — Each layer of the medium should have a volume approximately one fourth that of the total for the jar. The bottom layer is sand (B), the middle is leaf mold (C), and the top layer is loam (D).

c. Notes

(i) Place the worms in the wormery along with some dead leaves, lettuce, carrots, etc. Keep the contents damp.

A7. Jar Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jar	1	Large Glass Jar (A)	4 liter capacity
(2) Water Bottle	1	Glass Tube (B)	25 cm long, 0.5 cm outside diameter
	1	Vial (C)	50-100 ml capacity
	1	1-Hole Stopper (D)	To fit vial

b. Construction

(1) Jar

Use a large capacity glass jar (A) with a metal or plastic lid. Punch several holes in the lid for ventilation. Make certain one of the holes is slightly larger in diameter than the glass tube (B) used in the water bottle.

(2) Water Bottle

Heat the glass tube (B) about 7 cm from one end and make a slight bend in it (about 30°). Fire polish this end until the opening constricts very slightly. Insert the other end of the tube through the one-hole stopper (D), and plug the vial (C) with the stopper. Insert the completed water bottle through a hole in the lid of the jar. Be sure the tip of the glass tube is low enough for the animals to reach.

c. Notes

(i) This cage is designed for small mammals like mice or gerbils. Spread a layer of sawdust or newspaper shreds on the bottom to absorb wastes. Fill the water bottle and the animals soon learn to lick water from the end of the tube. Pieces of food can be dropped through the holes in the lid.

(ii) This cage is meant to be a temporary, not permanent, container for small mammals. Large jars of 4 liter capacity may be obtained from restaurants and other places which buy food in large quantities.

A8. Box Wormery

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Box	1	Wood (A)	25 cm x 25 cm x 1 cm
	2	Wood (B)	25 cm x 2 cm x 15 cm
	1	Wood (C)	21 cm x 2 cm x 15 cm
(2) Glass	1	Window Glass (D)	23 cm x 15 cm x 0.3 cm

b. Construction

(1) Box

With a saw, cut a groove 1.0 cm deep and 1.0 cm from the end of the two pieces of wood (B). These grooves should be slightly wider (about 0.4 cm) than the glass (D) used. Nail these two pieces and the piece (C) to the base (D) to form an open-ended box with the two grooves facing each other.

(2) Glass

Insert the glass (D) into the grooves in the sides of the box. The box wormery is now complete.

c. Notes

(i) Put a 5 cm deep layer of sand in the box, cover this with 5 cm of leaf mold, and finally cover this with about 5 cm of loam. Add worms, dead leaves, pieces of lettuce and carrots to the top. Cover the glass front with dark paper

or cloth and keep the soil damp. After several days, worms and tunnels should be visible when the paper or cloth is removed.

(ii) There is no real need for the glass plate to be removable so all the joints between the wood and glass can be sealed with waterproof sealant (e.g., pitch, caulk).

(iii) If it is desired to simply raise worms rather than observe them, then the glass may be omitted and any suitable box can be used for the wormery.

A9. Ant Observation Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	2	Wood (A)	13 cm x 2 cm x 0.7 cm
	1	Wood (B)	23 cm x 2 cm x 0.7 cm
	2	Glass Plates (C)	23 cm x 15 cm x 0.3 cm
	6	Tape (D)	19 cm x 2 cm
	3	Tape (E)	27 cm x 2 cm
(2) Support	2	Wood (F)	7 cm x 2 cm x 2 cm
(3) Cover	1	Wood (G)	19 cm x 2 cm x 0.7 cm
	1	Nail (H)	4 cm long, 0.3 cm diameter

b. Construction

(1) Body

Glue, nail, screw or otherwise fasten the two short pieces of wood (A) to the ends of the longer piece (B). When the glue has dried, place the wood frame between the two pieces

of glass (C) forming a "sandwich". Use the six short pieces of tape (D) to tape each end together and use the three long pieces of tape (E) to tape the bottom.

(2) Support

Cut a notch 1.4 cm wide and 1.0 cm deep into the center of each wooden support (F). Set the body into place.

(3) Cover

Drill a hole approximately 0.3 cm in diameter through the middle of the piece of wood (G). Cut off a small portion of each end so that the ends are slightly tapered. This cover should now effectively seal the body, and the wedge shape of the cover insures that it need not be perfectly accurate in order to seal the cage. Complete the ant observation cage by sticking the nail (H) in the hole.

c. Notes

(i) Prepare the cage for use by filling it to within 2 - 3 cm of the top with soil. The soil should be firm, but not tightly packed. Add the ants (include a "queen" ant), and feed them by dropping moistened sugar, bread crumbs, etc., through the hole in the cover. Keep the cage covered when not actually observing the ants as this will encourage their tunneling activity.

(ii) The soil ought to be kept moist, so the cage should be taped with waterproof tape. Taping allows the cage to be easily dismantled, cleaned and reassembled.

(iii) Ant observation cages of different dimensions from those given here can be made, but the basic design need not be altered.

A10. Glass Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Plywood (A)	30 cm x 30 cm x 1.0 cm
	4	Wood (B)	20 cm x 2 cm x 2 cm
	8	Wood (C)	24 cm x 2 cm x 2 cm
(2) Glass	32	Nails (D)	2.5 cm long
	4	Glass (E)	25.5 cm x 18.75 cm x 0.3 cm
	1	Glass (F)	25.5 cm x 25.5 cm x 0.3 cm

b. Construction

(1) Frame

Use the plywood (A) as the cage base. Screw the four short pieces of wood (B) to the base from the back side of the base so that each of their edges is 1.0 cm from the edge of the base. Nail four of the remaining pieces (C) to the base (A) and uprights (B), between the uprights and 1.0 cm from the edge of the base.

Drill three holes (0.2 cm in diameter) through each of the four remaining pieces of wood (C). Space the three holes about 6 cm apart and 0.5 cm from one edge. In one of these pieces of wood, drill two additional holes 0.2 cm in diameter. Drill them 0.5 cm from the same edge the other three holes are near, but only drill them halfway through the wood. Nail these four pieces to the uprights so that the holes are parallel to the base, and the holes must be closest to the top edge of the wood rather than the bottom. These three holes serve to ventilate the cage.

(2) Glass

Position one of the glass pieces (E) against the side of the frame so that it overlaps the edges of the frame by about 0.75 cm on all three sides. Drive four nails (D), two per vertical side, into the frame as close to the glass as possible. Only drive them in about halfway and remove the glass. Bend each nail over at right angles, and replace the glass. The nails should overlap the glass and hold it upright against the frame. Nail two more nails (D) above the glass and bend them down in a similar manner to keep the glass side firmly in place. Be

Side View

careful not to break the glass.

Fasten the remaining piece of glass (F) to the top in a similar manner as was done with the sides. Nail six nails (D), two per side, and bend them over to hold the glass in place. Put two nails in the holes in the remaining side of the frame. These two nails should slip easily in and out the holes so that they can be removed and the top glass plate removed by sliding it out from under the bent nails. Do not bend these last two nails.

c. Notes

(i) This cage is designed primarily to house small reptiles (especially lizards and snakes) and other small, non-gnawing animals. The bottom of the cage can be filled with 1.5 - 2 cm of clean sand or gravel. If burrowing animals are to be kept, build the bottom of the frame higher so that the sand or gravel may be made deeper. Water may be provided in a jar lid and food simply dropped in from the top.

(ii) The dimensions of this cage can easily be altered depending on the number, size, and habits of the animals to be housed in it.

(iii) If it is so desired, a metal tray can be fashioned for the bottom of the cage to hold the sand or gravel. This makes the cage much easier to clean as the tray can simply be lifted out of the cage, the sand or gravel cleaned by running it through a seive, and replacing it. The tray prevents the wood from absorbing liquid wastes and spilled water and food. The pattern given here will fit the cage as described above. (See illustration on next page.)

Fold the pattern along the dotted lines to the following shape.

Seal the inside corner joints with a waterproof sealant (e.g., pitch) and set the tray in place in the bottom of the cage. The flanges should overlap the bottom portion of the frame.

B. WOODEN CAGES

B1. Wooden Frame Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Wood (A)	25 cm x 25 cm x 1.0 cm
	6	Wood (B)	25 cm x 2 cm x 2 cm
	2	Wood (C)	21 cm x 2 cm x 2 cm
(2) Door	2	Wood (D)	27 cm x 3 cm x 1.0 cm
	2	Wood (E)	19 cm x 3 cm x 1.0 cm
	2	Hinges (F)	About 3 cm x 2 cm
	4	Nails (G)	2 cm long
	2	Rubber Bands (H)	--
(3) Screening	1	Wire Mesh (I)	24 cm x 24 cm
	3	Wire Mesh (J)	26 cm x 24 cm
	1	Cloth (K)	85 cm x 25 cm
	1	Rubber Band (L)	--

b. Construction

(1) Frame

Glue, nail, or screw four of the long pieces of wood (B) to the four corners of the square piece (A) to form the uprights of the cage. Nail the two remaining long wooden pieces (B) to the tops of adjacent uprights. Then, nail the two short pieces (C) into place to complete the basic cage frame.

(2) Door

Glue, nail, or screw the short pieces of wood (E) between the long pieces (D) to form the frame for the door. Attach two small hinges (F) to the back of the door.

Front View

Next, fasten the door to the frame by use of the two hinges.

Detail

To keep the door shut, hammer nails (G) at both top and bottom of the door and frame. When the door is shut, wrap a strong rubber band (H) around each set of nails to keep the door shut.

(3) Screening

Side View

Attach the three pieces of screening (J) (cloth mesh may also be used) to the three sides and the fourth (I) to the top of the frame by gluing or tacking them in place. Liberal use of glue helps seal the joint between the screen and wood, especially if cloth mesh is used instead of wire mesh.

Sew the piece of cloth (K) along the short (25 cm) edge to make a kind of tube or "sleeve". Then, glue one end all around the inside edge of the door, making certain there are no gaps in the glue seam.

Detail

Side View

To complete the cage, close and latch the door, twist the protruding end of the cloth tube tight, and close it off with the rubber band (L).

c. Notes

(i) The door can be opened to allow the cage to be cleaned, rearranged, etc. However, when the cage contains insects, items such as food, water, and the insects themselves can be put into and taken out of the cage by undoing the rubber band, slipping one hand through the cloth sleeve into the cage, and holding the cloth tightly around the arm in the sleeve with the other hand; this method prevents the insects from escaping.

(ii) See insect cages VI/A3 and VI/A4 for making watering and feeding devices for insects.

(iii) Since cloth is used for the sleeve and may be used for the sides, keep only insects or other small animals which are unable to chew their way through cloth in this cage.

B2. Wire Cage

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Plywood (A)	25 cm x 30 cm x 0.5 cm
	4	Wood (B)	20 cm x 2 cm x 2 cm
	4	Wood (C)	21 cm x 2 cm x 2 cm
	3	Wood (D)	26 cm x 2 cm x 2 cm
	4	Wood (E)	16 cm x 2 cm x 2 cm
(2) Tray	1	Sheet Metal (F)	30 cm x 30 cm x 0.05 cm
(3) Door	2	Wood (G)	28 cm x 3 cm x 1.0 cm
	2	Wood (H)	18 cm x 3 cm x 1.0 cm
	1	Wire Mesh (I)	28 cm x 18 cm
	6	Nails (J)	2.5 cm long
(4) Wire Mesh	1	Wire Mesh (K)	23 cm x 62 cm
	1	Wire Mesh (L)	23 cm x 28 cm
	1	Wire Mesh (M)	20 cm x 26 cm
(5) Water Bottle	1	Vial (N)	50-100 ml capacity
	1	1-Hole Stopper (O)	To fit vial

1	Glass Tube (P)	10 cm long, 0.7 cm outside diameter, 0.5 cm inside diameter
1	Stiff Wire (Q)	About 20 cm long

b. Construction

(1) Frame

Nail or screw the four 20 cm pieces of wood (B) onto the four corners of the piece of plywood (A) used as the base. Make certain they are even with the edges of the base. Next, nail the four 21 cm pieces (C) into position between the upright pieces, two at each side of the cage. Nail the lower ones to both the base and uprights. Nail the three 26 cm pieces (D) between the uprights, one at the top front, and two in the rear, top and bottom. Finally, nail the four 16 cm pieces (E) into position at the two back corners of the cage, one on each side of each upright.

(2) Tray

Cut the sheet metal (F) to the given pattern. Bend up the sides along the dotted lines and bend down the flange at the front. Seal the corners with a waterproof sealant (e.g., pitch). The tray should slide easily into the cage and protrude from the front for 1.0 cm.

(3) Door

Make the door from the four pieces of wood (G,H) by using half-lap joints. This simply involves cutting away half the piece of wood where the two pieces to be joined overlap.

Nail the wire mesh (I) to the back of the door making certain that it covers all wood portions completely to discourage gnawing animals like mice. If possible, use mesh with openings about 0.5 cm square rather than regular wire screening that is used in house screens.

Front View

To form a holder for the door, first hammer two nails (J) into the front of the frame at a level even with the top of the tray. Drive them in 1 - 1.5 cm but do not bend them. Set the door on these two nails and be certain that it completely covers the opening. Nail two nails (J) on each side of the door as close to it as possible and bend them over so that they hold the door in an upright position. The door should slide easily in and out of position. Remove the door while completing the cage construction.

(4) Wire Mesh

Mesh (K)

Fold the long piece of wire mesh (K) (again, use the 0.5 cm square size if possible) to the shape shown. Then, nail the 20 cm piece (M) into position to seal off the rear of the cage. Next, nail the folded piece (K) into position so that

Cross Section View

the sidepieces cover the sides of the cage completely. The bottom of the screen will be 2 cm above the floor of the cage (actually, it will be level with the top edge of the tray). Properly done, wire mesh should cover the inside of the cage so that no wood is exposed. Finally, nail the remaining piece of mesh (L) onto the top of the cage.

(5) Water Bottle

Begin the water bottle by bending the glass tube (P) in the middle to about a 45° angle. Fire polish one end until the opening constricts very slightly. Insert the other end of the tube into the stopper (O). Fill the vial (N) with water and seal the opening with the stopper.

When the vial is upside down water should flow down into the tube and stop at the end. One may have to tap the tube lightly with a finger to break up air bubbles in the tube.

Hanger (Q)
(Vial not shown
for clarity)

To make a hanger for the water bottle, use the piece of stiff wire (Q). Twist the wire around the stopper, then bend the loose ends as shown. The water bottle can then be hung on the outside of the cage with the glass tube sticking through the wire mesh. Animals such as mice and gerbils soon learn to lick the end of the tube to obtain water.

c. Notes

(i) This cage is intended for long-term housing of small mammals. Cover the screen floor with shredded newspaper or sawdust. Wastes fall through the screen floor onto the tray so they can easily be removed. Food can be simply put into a jar lid or shallow tin can.

(ii) The basic design of this cage can be retained and the dimensions altered to accommodate other animals, especially birds. Remember to provide the basic requirements for each different type of animal (e.g., perches for birds).

(iii) If space is limited, these cages will stack one upon the other. However, the door must be hinged to swing open if it is undesirable to unstack them each time a lower cage is to be opened.

C. TEMPERATURE CONTROLLED CAGES

C1. Vivarium

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	1	Plywood (A)	60 cm x 45 cm x 1.0 cm
	1	Plywood (B)	43.5 cm x 20 cm x 1.0 cm
	2	Wood (C)	20 cm x 2.5 cm x 2.5 cm
	1	Wood (D)	38.5 cm x 2.5 cm x 2.5 cm
	2	Wood (E)	55.5 cm x 2.5 cm x 2.5 cm
	2	Wood (F)	4 cm x 4 cm x 2 cm
	4	Sheet Metal (G)	5 cm x 21 cm x 0.05 cm
	2	Sheet Metal (H)	40 cm x 5 cm x 0.05 cm
(2) Dividers	2	Wood Dowels (I)	42 cm long, 0.75 cm diameter
	2	Cloth (Cotton) (J)	38 cm x 25 cm

(3) Heat Source	1	Plywood (K)	44 cm x 16 cm x 1.0 cm
	1	Hardboard (L)	16.5 cm x 45 cm x 0.3 cm
	1	Plywood (M)	20 cm x 44 cm x 0.5 cm
	2	Plywood (N)	16.5 cm x 21 cm x 0.5 cm
	2	Wood (O)	20 cm x 4 cm x 1.0 cm
	1	Wood (P)	36 cm x 4 cm x 1.0 cm
	2	Sheet Metal (Q)	14 cm x 5 cm x 0.05 cm
	1	Plywood (R)	44 cm x 15 cm x 0.5 cm
	1	Light Bulb Socket (S)	Varies
	1	Light Bulb (T)	Varies
	1	Electric Cord (U)	150 cm long
	1	Plug (V)	Varies
(4) Screen	4	Bolts (W)	8 cm long, 0.5 cm diameter
	4	Wing Nuts (X)	0.5 cm inside diameter
	1	Wire Screen (Y)	20 cm x 45 cm
	2	Wood (Z)	21 cm x 3 cm x 0.5 cm
	2	Wood (AA)	39 cm x 3 cm x 0.5 cm
	2	Wood (BB)	45 cm x 3 cm x 0.5 cm
	2	Wood (CC)	15 cm x 3 cm x 0.5 cm
(5) Glass	1	Window Glass (DD)	59 cm x 44 cm x 0.25 cm
	2	Window Glass (EE)	19 cm x 59 cm x 0.25 cm
	2	Sheet Metal (FF)	12 cm x 4 cm x 0.05 cm

b. Construction

(1) Frame

Notches must be made in the two sidepieces (E) into which the dividers will be fit. Also, holes need to be drilled through the end (D) and the two uprights (C) through which the bolts hold the frame, screen, and heat source are put. However, these holes should be drilled when the three components (frame, screen, heat source) are held together in place with clamps in order to insure that the holes will be aligned.

Corner Blocks (F)

Nail, screw and/or glue the endpiece (B) to the base (A), flush to one edge and 0.75 cm from the other two edges. Nail two uprights (C) to the base, flush to the opposite end and each 0.75 cm from the outside edge. Nail the sidepieces (E) into position between the uprights and endpiece, and also nail the end (D) between the two uprights.

Two square pieces of wood (F) cut into triangular shapes are used as corner blocks to provide additional support and strength.

To provide guides for the glass, six rectangular pieces of aluminum sheeting (G, H) (0.05cm thick) are required. They are folded to the shape shown. Four (G) are nailed to the upright and endpiece. The remaining two (H) are nailed to the end and endpiece. These guides should be fastened in such a way as to provide approximately a 0.75 cm gap between wood and metal so that the glass can slide easily in and out.

(2) Dividers

The dividers are simply made with wooden dowels (I). A piece of cotton cloth (J) is sewn around the dowel, and hangs down to within 1 or 2 cm of the base. The dividers (two are needed) are fit into the notches in the frame sides.

(3) Heat Source

Use the piece of plywood (K) as the base of the heat source. Fasten the two plywood pieces (N) to the ends of the base and the third plywood piece (M) to the back. Nail two of the wood strips (O) to the base and ends, and nail the remaining strip (P) between these two pieces (O).

Nail the piece of hardboard (L) to the top of the frame to enclose it. This hardboard should be the perforated type with 0.5 cm holes spaced every 2.5 - 3.0 cm. If such hardboard is not available, it can easily be made by making holes in regular board. Holes must also be made in the heat source, but again, these should be

drilled when the frame, screen, and heat source can all be held together with clamps to insure alignment of the holes. Drill another hole in the back to allow the wire to the light bulb socket to run through.

Two guides (Q) are needed for the ventilation board, and are nailed to the sides of the heat source. Make these like the glass guides described in construction step (1). The ventilation board (R) is made of thin plywood slightly shorter in length and width than the top of the heat source. It should slide easily in and out between the guides (Q).

Finally, fasten a light bulb socket (S) in the middle of the heat source. Wire a plug (V) to the socket with the wire (U) and lead it out of the box through a small hole drilled in the back. Screw a bulb (T) in place.

(4) Screen

The screen is made with eight pieces of wood. Form two rectangular frames. Make one by nailing two pieces of wood (CC) between the two pieces (BB), and the second frame by nailing two pieces (AA) between the shorter pieces (Z). The aluminum screening (Y) (wire mesh) is fastened between the two frames with nails, and the frames are nailed and glued

(5) Glass

together. The four holes for the connecting bolts (W) will be made when the three components (frame, screen, heat source) are clamped together, and the holes are drilled through all three parts at once.

The heat source, screen, and frame are connected together with the bolts (W) and wing nuts (X).

Three glass plates are not shown in the main illustration in order to preserve clarity. However, the two side plates (EE) are made from standard window glass (0.2 cm in thickness). They fit between the glass guides on the frame sides. The top plate is also window glass (DD). The top plate of glass fits between the two glass guides on the top of the frame. Any of the three pieces of glass should slide easily in and out of place when the other two are in position. Additionally, air gaps should be kept to a minimum.

Finally, two pieces of aluminum sheeting (FF) can be folded to the shape shown and slipped over the top edge of one of the side pieces of glass (EE). These pieces of aluminum then act as stops to keep the top glass plate (DD) from sliding out.

c. Notes

(i) The vivarium is a cage in which the cloth dividers are used to loosely partition the interior into three chambers. The heat source employs light bulbs as the heating elements. A desirable result would be to maintain an even temperature gradient (i.e., 35°, 30°, 25° C) in the three chambers so that animals placed in the vivarium could seek their own optimal temperature level. For instance, the temperatures given above would imply that it was thought that the optimal environmental temperature for a given animal was 30°C (the temperature maintained in Chamber B). In this case, even if the vivarium were placed out-of-doors and subjected to temperature fluctuations of ± 5°C, one of the chambers would still maintain the 30°C level (e.g., temperatures in the vivarium might be depressed to <u>30</u>°, 25°, 20° or elevated to 40°, 35°, <u>30</u>° C). In order to insure that the desired temperature is maintained in at least one chamber, it may be necessary to increase the number of chambers from the three used in this experimentation. In fact, all the conclusions given here must be qualified by the limited nature of the experimentation.

(ii) Following construction of a vivarium, experimentation was carried out to determine which variables affect the establishment of the temperature gradient, and how these variables affect this gradient, both separately and in combination. Variables found to influence the temperature gradient included bulb size (wattage), divider material, height of the dividers above the floor of the cage, use of a reflector in the heat source and ambient (room) temperature.

(iii) Generally, increasing the bulb size (wattage) caused a marked increase in temperature in Chamber A, less so in Chamber B, and little or no change in temperature in Chamber C. The result was that the temperature gradient, rather

than increasing in equal increments (i.e., 34°, 30°, 26° C), tended to increase in unequal increments (e.g., 36°, 26°, 23° C).

(iv) The material from which the dividers are made was found to have little effect on the temperature gradient maintained in the cage, but the amount of space left between the bottom of the dividers and the vivarium floor did have a compacting effect on the temperatures, i.e., bringing those in Chambers A and C closer to that in B.

(v) As might be expected, using a reflector in the heat source caused an overall rise in temperature in the vivarium. The last variable to be investigated, ambient (surrounding) temperature, was seen to have a profound influence on the internal temperatures in the vivarium, and is probably the most important variable to be considered. No doubt, the vivarium walls will have to be altered using better insulating materials (e.g., wood rather than glass) in order to reduce the influence of the ambient temperature.

(vi) Some other variables which were not investigated also may have an effect on temperature control. Among these is the material in the screen between the heat source and cage itself. It was aluminum screening for all the experimentation described here, but may well have different effects if it were made from steel rods or other materials. The type and amount of ventilation will also be an influence.

The dimensions of the vivarium are also important since a larger cage will obviously be harder to heat and maintain. The number and size of the chambers are variables to be reckoned with.

Finally, the most important factor will be the animals and their requirements. Testing must be done to see if a reasonable range of temperatures can be maintained for a variety of animals (e.g., baby chickens, mice, lizards, etc.). If experiments are to be run involving the determination of optimal temperature requirements for a particular animal, the range of temperatures provided must be narrow enough so that there will be some assurance that the animal has indeed chosen its favorite temperature, and not simply chosen the lesser of three evils. For example, if the optimal temperature for a certain lizard is thought to be 30°C, then the range should be 30°C plus or minus 2° or 3°C rather than plus or minus 6° or 8°.

(vii) Experimentation was also done with the cloth partitions removed, making the vivarium a single chamber. Three conditions were checked using three different bulb wattages (60, 100, 175). In the first condition, the vivarium was used as described above, only without the cloth partitions. In the second condition, one half of the glass top was removed and replaced by wood, and in the third case, the

entire top was wood, leaving only the front piece of glass. In all three instances, the aluminum foil reflector was used, and the ventilated top of the heat source was fully closed. The results of this experimentation are tabulated below.

Table I

Condition	Wattage	Vivarium Temperature (°C)	Room Temperature (°C)
Top Completely Glass	60	26	22
	100	28	22
	175	33	22.5
Top One Half Glass, One Half Wood	60	26	22
	100	29	22.5
	175	38	24
Top Completely Wood	60	26	22
	100	30	22
	175	37	23

As the data show, there appears to be little significant difference in the various temperatures, although the additional wood does help hold the heat slightly better than the all glass top.

The vivarium will serve adequately as a controlled temperature environment as long as the ambient (room) temperature is kept relatively constant.

(viii) If the vivarium is to be used in a room where the outside temperature varies greatly, it is desirable to control its internal temperature more accurately. Therefore, use the thermostat, item VI/C3. Wire the heat source to the thermostat which should be mounted in the back panel of the vivarium if no wood is used in the top. Keep the thermostat as far from the heat source as possible. In addition, a screen or other protective device must be placed over the thermostat to prevent the animals (and students) from touching the exposed portions of the thermostat which carry current of 110 volts.

C2. Egg Incubator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Box	2	Wood (A)	23 cm x 20 cm x 1.5 cm
	2	Plywood (B)	20 cm x 36 cm x 1.0 cm
	1	Plywood (C)	25 cm x 36 cm x 1.0 cm
	1	Wood (D)	23 cm x 2 cm x 2 cm
	2	Wood (E)	14 cm x 1.0 cm x 1.0 cm
	1	Wood (F)	23 cm x 1.0 cm x 1.0 cm
	1	Plywood (G)	19 cm x 25 cm x 1.0 cm
(2) Glass Front	2	Glass (H)	18 cm x 10 cm x 0.3 cm
	2	Wood Strips (I)	10 cm x 0.5 cm x 0.5 cm
	2	Wood Strips (J)	17 cm x 0.5 cm x 0.5 cm
	2	Wood (K)	23 cm x 2.5 cm x 2 cm
	2	Wood (L)	15 cm x 2.5 cm x 2 cm
	4	Screws (M)	Approximately 2 cm long
	2	Rubber Bands (N)	--

(3) Heat Reflector	1	Plywood (O)	23 cm x 15 cm x 1.0 cm
	1	Aluminum Foil (P)	28 cm x 20 cm
(4) Tray	1	Wire Mesh (Q)	26 cm x 20 cm
	4	Bolts (R)	Approximately 2 cm long
	4	Nuts (S)	To fit bolts
(5) Heat Source	2	Bulb Sockets (T)	10 cm diameter (base)
	4	Bolts (U)	Approximately 3 cm long
	4	Nuts (V)	To fit bolts
	1	Electrical Wire (W)	Approximately 100 cm
	1	Plug (X)	--
	2	Bulbs (Y)	--

b. Construction

(1) Box

Nail or screw the two sidepieces of plywood (B) to the two pieces of wood (A) serving as the top and bottom of the box. Nail or screw the back (C) into position. Small ventilation holes (0.4 cm diameter) should be drilled along the tops of the sidepieces (B).

Make certain the crosspiece (D) fits very tightly, and nail or screw it into place. Nail or glue the wood strip (F) to the top (A), 2 cm from the front edge of the top. Likewise, nail or glue the other two wood strips (E) to the sidepieces (B), 2 cm from their front edges between the top (A) and cross-piece (D).

The front panel (G) is screwed into place so it may be easily removed to permit completing the construction of the incubator, and to permit changing the light bulb in the heat source.

(2) Glass Front

Make the frame for the glass front with half-lap joints (see drawing). Use this type of joint to connect the two short pieces of wood (L) to the two longer ones (K). Glue the two wood strips (I) down the center of the inner surface of the short wood pieces (L), and similarly, glue the longer strips (J) down the center of the inner surface of the long pieces (K). These thin strips serve to separate the two pieces of glass (H) which can now be glued into place with epoxy resin cement.

Half-lap Joint

Front View

Cross Section

The glass front should fit tightly in the recess in the front of the box. To hold it in place, fasten one screw (M) on each side of the frame of the glass front and each side of the box adjacent to the glass front. Rubber bands (N) stretched tightly between adjacent screws should hold the glass front firmly in position.

(3) Heat Reflector

Front View

Cover the lower surface of the plywood (O) with the aluminum foil (P) and nail the heat reflector into position as shown. Be sure the rear edge is touching the back (C) of the box.

(4) Tray

Tray (Diagram)

Use the wide (0.5 cm square) wire mesh (Q) for the tray and fold it so there is a 1.5 cm edge all around. Fasten it to the inside of the box by pinning the side edges of the mesh to the sides of the box with the nuts (S) and bolts (R). Obviously holes will have to be drilled through the sides of the box to permit passage of the bolts. The rear edge of the tray should touch the back (C) of the box.

Front View

(5) Heat Source

Front View

Drill four holes in the back of the box near the bottom through which the bolts (U) will be passed to hold the bulb sockets (T) in position. Wire the sockets together in parallel with short lengths of wire (W) and pass the remaining wire out of the box through a fifth hole drilled in the back. Wire the plug (X) in place, and tighten the nuts (V) onto the bolts (U) now that the bulb sockets are wired. Finally, place the desired number and power (wattage) of light bulbs (Y) in the sockets.

c. Notes

(i) Use the egg incubator in the study of the embryology of chicken or other eggs. The double glass front permits visual observation of the eggs on the tray without undue heat loss.

(ii) The temperature in the incubator will remain constant using varying

wattages of light bulbs as long as the room temperature is relatively constant (see the table).

Watts	Incubator Temperature (°C)	Room Temperature (°C)
40	37.5	23.0
60	46.0	25.5
80	51.0	23.0
120	67.0	23.0

(iii) The thermostat (VI/C3) should be used with the incubator to insure that the internal temperature maintains itself at the correct level. Mount it in the top of the incubator, protected by a wire screen which will prevent hatchlings (and people) from touching the live wires. In fact, if the incubator is definitely to be used with the thermostat, increase the height of the top above the egg tray to insure that the hatchlings cannot touch the thermostat.

C3. Thermostat

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Platform	1	Wood (A)	10 cm x 10 cm x 1.0 cm
	1	Wood (B)	6 cm x 6 cm x 1.0 cm
	1	Wood Strip (C)	3 cm x 2 cm x 0.5 cm
	1	Wood Strip (D)	2 cm x 1.5 cm x 0.5 cm
(2) Bimetallic Strips	2	Bimetallic (Brass/Steel) Strips (E)	Approximately 3.5 cm x 0.5 cm
	1	Platinum Wire (F)	#20, 3 cm long
	2	Bolts (G)	0.2 cm diameter, 4 cm long
	2	Nuts (H)	0.2 cm internal diameter
	4	Washers (I)	--
	1	Bolt (J)	0.3 cm diameter, 5 cm long
	1	Nut (K)	0.3 cm internal diameter
	1	Washer (L)	1 cm external diameter
	1	Plastic Tube (M)	0.3 cm internal diameter, 0.5 cm long
	--	Insulation Tape (N)	--
(3) Electrical System	1	Capacitor (O)	0.01 microfarads
	1	Roll of Copper Wire (P)	#20

1	Bolt (Q)	0.3 cm diameter, 2.5 cm long
2	Nuts (R)	0.3 cm internal diameter
1	Double Electrical Cord (S)	300 cm long
1	Plug (T)	110 volt

b. Construction

(1) Platform

Glue the smaller wood piece (B) to the middle of the larger one (A). Next, glue wood strip (D) at one end of the other wood strip (E), and glue this resulting section near one edge of wood square (B).

(2) Bimetallic Strips

Drill a small hole (0.2 cm diameter or smaller) in one end of each bimetallic strip (E). Purchase these strips locally from a radio or electrical shop. Place a short piece of the platinum wire (F) through this hole and with a hammer, flatten each protruding piece of the wire flat as if the wire were a tiny rivet. Place a small drop of solder on the flattened portion of wire on the steel side of the bimetallic strip to insure good electrical contact. Alternatively, drill two very small holes in the end of each bimetallic strip, those in one strip in line with the short side of the strip and those in the other in line with the long side of the strip (see illustra-

Side View

Top Views

Side View

tion). Place one end of a short piece of the platinum wire through each hole from the brass side of the strip and solder these ends to the steel side of the strip to provide good electrical contact. Flatten each wire slightly with a hammer to help make a greater surface area for electrical contact. Regardless of the manner in which the platinum is fixed to the end of the bimetallic strips, drill a small (0.2 cm diameter) hole in the opposite end of each strip. Also, make certain no solder is on the brass side of the bimetallic strips since this is likely to contaminate the surface of the platinum contacts.

Next, drill two holes (0.2 cm diameter) through the platform, one through all four pieces of wood and the other through all but piece (D). Attach the bimetallic strips to the platform with the two bolts (G), two nuts (H), and four washers (I) as shown. The platinum contact point of the lower strip should face up while that of the upper strip should face down.

Top View

Pivot the free ends of the bimetallic strips toward one another so that the platinum contact points will touch one another when the strips are pressed together.

Side View

Drill a hole (0.3 cm diameter) through the platform directly below the middle of the lower bimetallic strip. Inset the nut (K) into the outside wood piece (A) directly over the hole. Thread the bolt (J) through the nut and hole. Place the piece of plastic tubing (M) on the end of the bolt (J) to prevent electrical contact between the bolt and metallic strip. Solder the washer (L) to the notch in the bolthead and cover both thoroughly with insulation tape (N). Make absolutely certain the bolt is completely insulated from the bimetallic strip as it will carry 110 volt current.

(3) Electrical System

Top View

Purchase the capacitor (O) locally, and connect it across the bimetallic strips. Cut a hole (6 cm x 6 cm) into the top of the container which is to be heated. The thermostat platform should fit firmly in the hole with the bimetallic strips beneath the platform.

Wiring Diagram

Use one piece of copper wire (P) to connect one of the bimetallic strips to one contact of the bulb socket of the heating source, and use another piece of the wire to connect the other bimetallic strip to a terminal [made from bolt (Q) and two nuts (R)] which must be put in the back of the cage or incubator which is to be heated. Then, connect the double electrical cord (S), with the plug (T) attached, to the terminal and the remaining contact on the bulb socket. The wiring circuit as shown in the diagram is now complete, and the thermostat is ready for use.

c. Notes

(i) It should be noted that due to lack of time the thermostat described here was tested out with the Microorganism Incubator (VII/A4) only. Care should therefore be taken to test the thermostat carefully when used in conjunction with either the Egg Incubator (VI/C2) or Vivarium (VI/C1).

(ii) It was noted that using the thermostat the temperature of the Micro-organism Incubator took about 25 minutes to stabilize.

Time Minutes	Cage Temperature °C
0	40.5
5	39.0
10	38.5
15	38.0
20	38.0
25	37.0
30	37.0 stabilized

(iii) Do not permit direct radiation from the heat source to fall on the thermostat, otherwise the thermostat will switch itself off before the air temperature has risen to the desired level. Where there is a possibility of direct radiation falling on the bimetallic strips of the thermostat make an appropriate shield to stop the radiation without restricting the circulation of air around the bimetallic strips.

VII. MICROBIAL GROWTH APPARATUS

A. BASIC APPARATUS

Included here are improvised versions of the equipment necessary to perform elementary investigations in microbiology. Information on culturing microorganisms should be obtained from standard texts on the subject.

A. BASIC APPARATUS

A1. Culture Flask

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bottle	1	Medicine Bottle (A)	About 100 ml or larger
	1	Cotton Plug (B)	--

b. Construction

(1) Bottle

Sterilize the bottle (A) and fill it 1/6 full of either liquid or gelatin culture medium. Stopper it with the cotton plug (B). If gelatin medium is used, lay the bottle on its side and allow the medium to set. Store the flask with the medium on the upper side of the flask so that no moisture film will form on the medium.

c. Notes

(i) Consult a standard microbiological text or source book for detail in working with bacteria and other microorganisms.

(ii) Use glass medicine bottles with flat sides if these are available.

(iii) Petri dishes are invaluable in working with microbes. See CHEM/V/A6 for instructions in making petri dishes.

A2. Sterilizer

(3) Rack (Not visible)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Top	1	Sheet Metal (A)	17 cm diameter, 0.075 cm thick
	1	Hinge (B)	3 cm x 2 cm
(2) Can	1	Tin Can (C)	15 cm diameter, 18 cm high
	4	Screws (D)	1.5 cm long
(3) Rack	1	Sheet Metal (E)	14.5 cm diameter, 0.075 cm thick

b. Construction

(1) Top

Cut the top from a circular piece of sheet metal (A). Leave three tabs to be bent down at right (90°) angles. The tabs are 1.0 cm long. Screw the small hinge (B) to the top directly opposite the middle tab.

(2) Can

Remove one end from the tin can (C). Attach the top to the can by means of the hinge. Most tin cans have a ridge around the edge so that when the top is closed, the three tabs should catch on this ridge and hold the top down rather firmly. Finally, screw the four screws (D) through the outside into the inside of the can, 9 cm from the bottom and spaced about 12 cm apart.

(3) Rack

Punch a number of holes into the sheet metal disc (E). Set this disc inside the can so that it is supported by the four screws extending into the can.

Side View
(Cross-section)

c. Notes

(i) To use the sterilizer, simply put 3 - 4 cm of water in the can and place the items to be sterilized on the rack. After the water has begun to boil, leave

the items in the steam for about 90 minutes.

(ii) If the can used is large enough, two or more racks can be made for it to allow a larger number of articles to be sterilized at the same time.

(iii) This sterilizer will kill most, but not all, common bacterial contaminants. If pure sterility is desired, an autoclave or ordinary pressure cooker is needed. Place the articles on a rack and autoclave or pressure cook them for about 20 minutes.

(iv) An alternate rack can be made by fastening a circular piece of wire mesh to a frame of stiff wire.

A3. Inoculating Needles

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Needle	1	Glass Tube (A)	0.3 cm diameter, 12 cm long
	1	Nichrome Wire (B)	10 cm long, #24 gauge

b. Construction

(1) Needle

Side View

Use soft glass tubing (A) with a small diameter bore. Insert about 2 cm of the wire (B) in one end of the tube and heat this end in a hot flame until the end of the glass constricts and holds the wire fast.

c. Notes

(i) The nichrome wire may be left straight or a 0.3 cm loop may be made in the end by twisting the wire around a 0.3 cm round object with pliers.

(ii) Use inoculating needles for transferring small amounts of bacterial cultures from one medium to another.

A4. Microorganism Incubator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame and Trays	3	Plywood (A)	35 cm x 32 cm x 1.0 cm
	1	Plywood (B)	33 cm x 32 cm x 1.0 cm
	1	Plywood (C)	35 cm x 36 cm x 1.0 cm
	6	Wood Strips (D)	30 cm x 1.5 cm x 1.0 cm
	3	Perforated Hardboard (E)	32.5 cm x 31 cm x 0.3 cm
(2) Heat Reflector	1	Plywood (F)	33 cm x 24 cm x 0.5 cm
	1	Aluminum Foil (G)	37 cm x 28 cm

(3) Heat Source	1	Egg Incubator, Heat Source (H)	VI/C2, Component (5)
(4) Door	1	Plywood (I)	35 cm x 36 cm x 1.0 cm
	2	Hinges (J)	Approximately 4 cm long
	8	Screws (K)	0.7 cm long
	6	Nails (L)	1 cm long
	3	Rubber Bands (M)	--

b. Construction

(1) Frame and Trays

Nail three of the wood strips (D) to each of two of the pieces of plywood (A) as illustrated to make the two side pieces of the frame. Nail the bottom edges of the completed side pieces to the wood (B) used as the base. Nail the back piece (C) into position as well as the top piece (A). When the frame is finished, the pieces of perforated card-board (E) which serve as the trays should slide easily into the frame on the wood strips (D).

Frame and Trays

(Front view)

(2) Heat Reflector

Cover one side of the plywood (F) with aluminum foil (G) to make the heat reflector. Nail the reflector into place 13 cm above the base (B) of the frame with a 4 cm gap between the rear edge of the reflector and the back (C) of the frame.

(3) Heat Source

Use two light bulbs as the heat source (H) exactly as described for item VI/C2, Component (5).

(4) Door

Fasten one edge of the plywood (I) to the side of the frame with the hinges (J) and screws (K) making certain the door shuts as closely to the frame as possible. Felt strips may be used as insulation between the door and frame if necessary, both to conserve heat loss and prevent the introduction of airborne contaminants. The door may be held closed by using rubber bands (M) which are stretched

between adjacent pairs of nails (M) in the frame and door.

c. Notes

(i) Use the microorganism incubator to provide a proper environment for growing bacteria, mold, and other cultures. The dimensions of the incubator as given are to enable each tray to hold nine (three rows of three) standard petri dishes (9 cm diameter).

(ii) If the incubator is used in a constant temperature room, the temperature in the incubator can be held relatively constant. Using the correct combination of bulbs will yeild an internal temperature close to that desired. Rather than drilling ventilation holes to cool the incubator if it is too hot, it might be better to paint part of the light bulbs with black paint to cut down their heat. Ventilation holes would allow contaminants into the incubator. The following gives a few examples of temperatures which can be maintained in the incubator.

Wattage	Incubator Temperature (°C)	Room Temperature (°C)
40	35.0	23.5
60	40.5	22.0
80	48.0	23.5

(iii) The thermostat (VI/C3) should be used with the incubator to insure that the internal temperature maintains itself at the correct level. Mount it in the top of the incubator, protected by a wire screen which will prevent persons from touching the live wires. In fact, if the incubator is definitely to be used with the thermostat, increase the height of the top above the uppermost tray in order to insure that people placing cultures in the incubator have less chance of touching the thermostat.

A5. Transfer Pipette

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pipette	1	Glass Tube (A)	35 cm long, 0.4 cm inside diameter

b. Construction

(1) Pipette

Hold one end of the glass tube (A) in a flame until the opening begins to constrict slightly. Remove it from the flame and let it cool when the opening is about 0.1 cm wide. To calibrate the pipette, a 10 cc (ml) syringe and short piece of rubber or plastic tubing is needed. Connect the ends of the pipette and syringe with the short (4 - 5 cm) piece of tubing. Fill the syringe and pipette with 7 or 8 cc of water and eliminate air bubbles by gently tapping the pipette. Hold the pipette vertically (syringe at the bottom) and withdraw the

syringe plunger until the water empties from the pipette. Note the position of the syringe plunger on the scale and reinject water into the pipette 0.5 ml at a time until a total of 5 ml is reached. At each injection, mark the position of the water meniscus with a triangular file to form a permanent scale.

c. Notes

(i) This pipette is used in transferring exact amounts of culture broth from one container to another. Draw broth into the pipette with mouth suction and force the liquid out by gently blowing through the tube.

(ii) If desired, numbers may be written by the filed marks to indicate the capacity at that point. These numbers will last longest if they are drawn with waxed crayons or other types of pencils designed for writing on glass.

A6. Transfer Chamber *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	2	Plywood (A)	60 cm x 40 cm x 0.75 cm
	1	Plywood (B)	60 cm x 20 cm x 0.75 cm
	2	Plywood (C)	40.75 cm x 40 cm x 0.75 cm
	1	Plywood (D)	61.5 cm x 18 cm x 0.75 cm
	2	Wood (E)	60 cm x 2 cm x 2 cm
	2	Wood (F)	24 cm x 2 cm x 2 cm
	2	Wood (G)	36 cm x 2 cm x 2 cm
	2	Wood (H)	16 cm x 2 cm x 2 cm
	2	Wood (I)	37.25 cm x 2 cm x 2 cm
	2	Wood (J)	28 cm x 2 cm x 2 cm
	2	Wood (K)	15 cm x 2 cm x 2 cm
	2	Wood (L)	6 cm x 2 cm x 2 cm
	1	Wood (M)	20 cm x 2 cm x 2 cm
	1	Aluminum Sheet (N)	25 cm x 11 cm x 0.05 cm
	1	Aluminum Sheet (O)	20 cm x 14 cm x 0.05 cm

*Adapted from Richard E. Barthelemy, et. al., Innovations in Equipment and Techniques for the Biology Teaching Laboratory, (Boston: D. C. Heath, 1964), pp 12-14.

(2) Glass 1 Window Glass (P) 28.5 cm x 58.5 cm x 0.3 cm

b. Construction

(1) Body

Plywood (A)

Begin the transfer chamber by cutting two holes into one of the large pieces of plywood (A). These will serve as ventilating holes when the chamber is enclosed.

Plywood (B)

Cut two holes in the piece of plywood (B) to serve as arm-holes. The size and distance apart of these holes may be varied to suit personal preferences.

Detail of Hole

Pattern

Cut the piece of aluminum sheeting (O) (other metal sheeting may be substituted) to the given pattern. Bend up the straight sides along the dotted lines to form two flanges, each 1.5 cm wide.

Half Cone

Roll the sheet metal (O) around a round object (e.g., a broom handle) until it takes the shape of a half cone.

Pattern

Similarly, bend up the two 11 cm sides of the other piece of aluminum (N), and roll it into a half-cylinder shape.

Half Cylinder

Nail the two aluminum pieces into position on the piece of plywood (A) in which the holes have been cut. Position the half cone directly over the triangular hole. Position the half cylinder so that its edges are even with the edges of the rectangular hole.

Nail the two wood strips (F) to the bottom edge of the back (A). Nail this in turn to the other plywood (A) used as the base.

Endpiece (C)

Cut the two pieces (C) as shown. Use these pieces as endpieces for the chamber.

Frame

Nail two strips (G), two strips (I), and one strip (E) to the back and base. Then nail the two endpieces (C) into position. Nail the two strips (K) to the front edge of the end, being careful to leave a 0.75 cm overlap for the frontpiece to fit into.

Next, nail the two strips (L), and the other strip (E) and strips (M) to the back of the frontpiece (B) as shown. Properly done, this piece can now be nailed into the front of the chamber. Be sure there is about a 1.0 cm overlap of the plywood over the 60 cm strip.

Cut one end of the wood strips (H) and wood strips (J) off at 45° angles

Cutaway View of One End

Nail one each of strips (J) and (H) to the endpieces (C) insuring they fit as shown in the drawing.

To complete the body, nail the last piece of plywood (D) to be the top, even with the edges of the back and sides.

(2) Glass

Simply rest the glass (P) on the frame made of the three wood strips, one on the front (E) and one each (J) on each endpiece. There should be no gaps between the glass and frame.

c. Notes

(i) Use the transfer chamber when transferring microbiological cultures from one container to another. With it, such techniques can be performed in a draft-free environment, thus reducing the possibility of airborne contamination. The students' or instructors' arms fit through the armholes in front while the glass permits all operations to be viewed easily.

(ii) The holes in the back serve for ventilation when the chamber is used with a bunsen burner.

VIII. PHYSIOLOGY MATERIALS

A. KYMOGRAPH

A wide range of physiological experiments using larger organisms may be performed using the kymograph.

B. VOLUMETER

In addition to identifying pressure changes, one may calculate the volume of gas exchanged with this equipment.

C. FERMENTATION TUBES

Fermentation rate is measured indirectly by the measurement of carbon dioxide.

D. MANOMETER

This apparatus enables one to identify changes in pressure within a biological system.

E. CHROMATOGRAPHY APPARATUS

Chromatography gives students useful insight into the techniques scientists use in investigating the biochemical composition of organisms.

A. KYMOGRAPH

A1. Kymograph

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	3	Wood (A)	25 cm x 2 cm x 2 cm
	1	Wood (B)	45 cm x 30 cm x 1.0 cm

	1	Sheet Metal (C)	2 cm diameter
(2) Drum Assembly	1	Tin Can (D)	4 liter (i.e., 15 cm diameter, 17 cm high)
	2	Sheet Metal (E)	17 cm x 2 cm x 0.05 cm
	1	Stiff Wire (F)	30 cm long, 0.2 cm diameter
	1	Tin Can (G)	5 cm diameter, 6 cm high
	3	Sheet Metal Screws (H)	1 cm long
	1	Glass Tubing (I)	0.4 cm diameter, 1.0 cm long
(3) Drive Assembly	1	Wood (J)	3 cm diameter, 0.5 cm thick
	1	Stiff Wire (K)	16 cm long, 0.2 cm thick
	1	Tin Can (L)	1 liter capacity
	1	Sand (M)	600 g
	1	Stiff Wire (N)	20 cm long, #20 gauge (0.1 cm diameter)
	1	String (O)	100 cm
	1	Tin Can (P)	4 liter capacity
	1	Pencil Stub (Q)	--
(4) Stylus Assembly	1	Wood (R)	25 cm x 2 cm x 2 cm
	1	Stiff Wire (S)	30 cm long, 0.2 cm thick
	1	Nail (T)	1 cm long, 0.2 cm thick
	1	Rubber Band (U)	6 cm long

b. Construction

(1) Support

Drill a hole through one of the pieces of wood (A) directly in its center. Drill another hole in the base board (B) directly below the hole in the upper strip of wood. Each hole should have a diameter of about 0.3 cm. The hole in the base should be drilled only halfway through. Nail two of the strips (A) to the base and nail the crosspiece (A) so that the two holes are

aligned. Finally, drill a 0.3 cm hole through the center of the disc of sheet metal (C) and nail the sheet metal to the base so that the hole in the base and the hole in the sheet metal are aligned.

(2) Drum Assembly

Try to select two tin cans (D,G) for the drum assembly which have both ends more or less intact. Otherwise, adjustments must be made to compensate for the open ends. At any rate, drill holes 0.3 cm in diameter in the center of both ends of each of the tin cans. Solder the two cans together making certain the holes in each align. If one of the ends of one or both cans has been removed, then the two cans can be screwed together with two sheet metal screws (H). Here, the illustrations show the situation when the small can (G) is intact and the large can (D) has one end removed.

Side View (Cross-Section)

To solve the problem of the open end of the large can (D), take the two sheet metal strips (E) and bend a flap down 1.0 cm from each end. Drill a 0.3 cm hole through each strip in its center. Put the two metal strips across the top of the can so that they are at right angles (90°) and their holes are aligned. The flaps can be adjusted so that the strips are

Metal Strip (E)

Front View

held tightly in place, or they may be soldered to the sides of the can.

Screw a short sheet metal screw (H) partway into the small can (G) to serve as an attachment point for the drive assembly string (O). Then, take the stiff wire (F) and insert it through the hole in the support, through the drum and through the glass tubing (I). Fire polish the ends of the glass to make them smooth. Finally, make sure the end of the wire rests in the hole in the base. The exposed end of the wire axle (F) may be bent for safety. The whole drum assembly should turn freely now.

(3) Drive Assembly

Top View Side View

Saw a groove all around the circumference of the wood disc (J) to make it act as a pulley. Drill a hole 0.3 cm in diameter through its center. Make the pulley mount from the stiff wire (K) by bending it to a "U" shape.

Pulley Mount (K)

Hammer the pulley mount into position on the base of the support after the pulley (J) has been slipped into place on the mount. It may be necessary

Top View

Side View

to drill small holes in the base for the pulley mount to fit into. The pulley and mount must be positioned at the front of the base directly in line with the drum assembly, and the pulley must extend beyond the edge of the base. The pulley mount can be bent over to insure that the pulley will extend out beyond the edge of the base, or alternatively, the holes into which the mount is inserted can be drilled at an angle.

Use the wire (N) to make a handle for the 1 liter can (L). Simply drill or punch two holes (0.2 cm diameter) near the top edge of the can, insert an end of the wire through each hole, and bend the ends up. Add the sand (M) to the can to act as ballast. This much weight should cause the can to float with only about 1 cm sticking above water level.

Make the 4 liter tin can (P) into a reservoir by removing its top. Tape the cut edges to prevent students from being cut. Drill or punch a small (0.15 cm diameter) hole at the bottom of the reservoir. Plug this hole with a pencil stub (Q) or piece of wood.

To set up the drive assembly, plug the hole in the reservoir (P) and fill it with water. Attach one end of the string (O) to the handle of the can (L) and make a small loop in the other end of the string. Put this loop around the screw (H) in the small tin can (G) under the drum, and wrap one turn of string around the small can. Run the string across the pulley (J), and float the tin can in the reservoir. Properly done, the float should lower gradually when the reservoir plug (Q) is pulled and water leaks out. As the float lowers, the string pulls on the drum causing it to slowly turn.

(4) Stylus Assembly

Top View

Side View of Stylus (S)

Top View

Front View

Nail or screw the stylus support (R) into position about 1.0 cm from one edge of the base, and 7 cm from the other edge. Make the stylus itself from the stiff wire (S) by making a loop in it about 5 cm from one end. Bend about 1 cm of the other end to a 90° angle to form the point. This point may be filed sharp to make a finer line. Position the stylus on the support by driving a nail (T) with a large head through the loop in the stylus. Drive the nail in only enough to allow the stylus to pivot freely without twisting a great deal. The position of the stylus point on the drum depends upon where on the stylus support the stylus is nailed, i.e., the higher the pivot point on the support, the higher on the drum the point of the stylus will strike. Finally, tie the rubber band (U) (break it at one point) to the upright support and to the middle of the stylus. Adjust this rubber band so that the stylus point strikes the drum firmly, yet lightly enough not to interfere with the rotation of the drum.

c. Notes

(i) To operate the kymograph, the drum must first be covered with a sheet of 17 cm x 50 cm glossy paper. Remove the drum from the support and attach the paper, glossy side out, to the drum with tape at the top and bottom. See that the seam where the two edges of the paper overlap is positioned in such a way that the stylus point will not catch on it (the seam) as the drum rotates.

Rotate the drum over a burning kerosene lamp. Hold the drum high enough so that the paper will not be scorched. Continue rotating it in the smoke until the drum is completely covered with carbon black. It takes about five minutes to cover the paper with carbon, requiring about 10 ml of kerosene. Handle the drum carefully since the carbon is easily scratched and rubbed off.

Replace the drum in the support, holding the stylus out of the way until the drum is in position. When the string to the float in the reservior is taut, the apparatus is ready to use.

(ii) One example of the use of the kymograph will be given here. Refer to the drawing below:

Put some warm water, yeast, and sugar in a bottle or test tube and seal the end with an expandable membrane (a piece of balloon rubber works well). Place the solution under the end of the stylus so that the tip of the stylus rests on the balloon. Start the drum rotating by pulling the plug from the bottom of the

reservoir. As the yeast respire, carbon dioxide gas is given off, gradually causing the balloon to expand, pushing the tip of the stylus up and its point on the drum down, leaving a scratch on the smoked paper. The slope of the scratched line indicates the rate of respiration of the yeast.

(iii) Use a clock, watch or other timing device to record time intervals (e.g., 30 seconds) and record these intervals by making a small mark on the drum each interval. These marks must be made as the drum revolves since the drum doesn't turn at a constant speed. This is because the velocity of the drum depends on the rate of flow of water from the reservoir which is not constant since the water pressure lowers as the depth lowers, thus causing the drum to slow down.

(iv) The stylus assembly may be altered to conform to requirements of other experiments. For example, the following illustration suggests how the stylus might be connected for studies of the heartbeat of an anesthetized frog:

Here, as the frog's heart contracts and expands, its motion is translated into up and down movements of the stylus. Remember, the stylus acts as a lever, and the amount of movement of the pointer depends upon the relative lengths of the portions of the stylus to either side of the pivot point.

(v) The rate at which the drum revolves depends directly upon how fast the float lowers in the reservoir. Therefore, in order to make the float, and thus the drum, go faster, it is necessary either to enlarge the reservoir outflow hole or make several such holes. Conversely, to make the float and drum slower, a reservoir with a large cross-sectional area is needed. In this case, even though the float still drops the same distance per one revolution of the drum, more water must flow out of the larger can to cause it to drop the same distance as in a smaller can.

(vi) If, for any reason, it is necessary that the drum turn two or more consecutive revolutions, remember that the reservoir must be deep enough to allow the float to drop the additional distance required. To be precise, for each revolution of the drum, the float must lower a distance equal to the circumference of the small can which the drive string is wrapped around.

B. VOLUMETER

B1. Volumeter

a. Materials Required

Components	Qu	Items Required	Dimensio..
(1) Vessel	1	Wide Mouth Glass Jar (A)	Size depends on organism to be studied
(2) Stopper	1	2-Hole Rubber or Plastic Stopper or Screw Cap (B)	To fit vessel
(3) Indicator and Scale	1	Glass Tubing (C)	30 cm long, 0.75 cm outside diameter, 0.5 cm inside diameter
	1	Stiff Paper Strip (D)	20 cm x 2 cm
(4) Pressure Regulator	1	Glass Tubing (E)	4 cm long, 0.75 cm outside diameter, 0.5 cm inside diameter
	1	Rubber Tubing (F)	4 cm long, 0.75 cm inside diameter
	1	Tapered Wood or Glass Rod Plug (G)	To fit rubber tubing

(5) Mesh Stand	1	Wire Mesh (H)	To fit vessel

b. Construction

(1) Vessel

Almost any container (A) from a vial, to a test tube, to a jar will suffice. It must be a convenient size for the organism to be studied - a liter jar would not be used for small insects - and should have a tight-fitting lid or stopper.

(2) Stopper

Depending on what vessel is used, the stopper (B) could be a two-hole rubber stopper or a tight-fitting screw cap with two holes drilled in for glass tubing. If a jar lid is used, the openings must be sealed with clay or paraffin after the indicator and pressure regulator have been inserted to prevent gas leak. Seal the underside, also.

(3) Indicator and Scale

Bend a piece of glass tubing (C) at a 90° angle as indicated. Cement a paper scale (D) to the long arm, and add a drop of colored detergent solution to serve as an indicator.

(4) Pressure Regulator

This is a piece of glass tubing (E), topped with a section of rubber tubing (F) and a plug (G). To regulate the position of the indicator, one simply releases the plug for a short period of time.

(5) Wire Mesh

Fold to
This Shape

Cut the wire mesh (H) slightly larger than the diameter of the vessel. Bend the ends down to form a support on which the organism will be placed.

c. Notes

(i) If one wishes to study the oxygen uptake per unit time of an animal, a CO_2 absorber such as KOH should be placed in the vessel under the wire mesh support. As the animal respires, O_2 is taken up and pressure in the tube falls, causing the bubble to move toward the vessel. If one knows the size bore in the tubing, then one can compute the volume of gas being exchanged by noting the distance that the indicator moves per unit time.

(ii) Transpiration may be measured by removing the pressure regulator from the top and inserting a broad-leaved plant cutting into the opening and sealing the joint with clay. Fill the container with water. Have the indicator bubble start at the open end of the sidearm tube. Allow the water to reach room temperature before setting the indicator bubble.

Volumeter Used as a
Transpirometer

C. FERMENTATION TUBES

C1. Balloon Fermentation Tube

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Vial	1	Medicine Vial, Test Tube, or Small Bottle (A)	50 ml capacity
(2) Balloon	1	Balloon (B)	To fit vial opening

b. Construction

(1) Vial	Any small container (A) with a mouth narrow enough to stretch the open end of the balloon over will suffice.
(2) Balloon	Fit the open end of the balloon (B) over the bottle.

c. Notes

(i) Fill the vial with a yeast-sugar solution before attaching the balloon. As CO_2 is given off, it collects in the balloon from which it can be taken for analysis.

C2. Durham Fermentation Tube

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jar	1	Wide-mouthed Glass Jar or Beaker (A)	500 ml capacity
(2) Vial	1	Medicine Vial or Test Tube (B)	50 ml capacity

b. Construction

(1) Jar

Any large wide-mouthed jar (A) or beaker will do. It must be large enough so that the small vial (B) can be covered completely with fermenting solution.

(2) Vial

The vial (B) should easily fit inside the jar where it can be completely submerged in solution.

c. Notes

(i) Fill both the jar and vial with a sugar-yeast solution. Place a finger over the open end of the vial, and invert it into the solution in the jar. As carbon dioxide is given off, some will be collected in the vial. This is useful for measuring relative amounts and rates of CO_2 production.

C3. Syringe Fermentation Tube

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Fermenting Bottle	1	Wide-mouth Jar (A)	300-500 ml capacity
(2) Rubber Stopper	1	2-Hole Rubber Stopper (B)	To fit fermenting bottle opening
(3) Vent Tube	1	Glass Tube (C)	6 cm long, 0.5 cm outside diameter
	1	Rubber Tube (D)	100 cm long, 0.5 cm inside diameter, 25-50 ml
	1	Plastic Syringe (E)	25-50 ml capacity

b. Construction

(1) Fermenting Bottle

Select a large glass or plastic container (A) with a wide mouth.

(2) Rubber Stopper

A two-hole rubber stopper (B) is needed to seal the bottle opening.

(3) Vent Tube

Bend the glass tube (C) to a right (90°) angle and insert it into one of the holes in the rubber stopper (B). Attach the rubber tubing (D) to the other end of the glass tube.

(4) Syringe

Insert the syringe nozzle (E) into the remaining hole of the stopper.

c. Notes

(i) One method of use for the syringe fermentation tube is as follows: Seal off the vent tube with a clamp or wood plug. Put about 250 ml of yeast solution in the fermenting bottle and put a known amount and concentration (e.g., 25 ml of 0.1 M) of glucose solution in the syringe. Inject the sugar water into the yeast solution and collect the carbon dioxide given off in the syringe.

(ii) Since it is difficult to accurately measure the amount of gas given off by the method described in (i) above, a further refinement is as follows: Connect the free end of the vent tube to a U-tube manometer (see VIII/D1). Fill the fermenting bottle with yeast solution, and add a measured amount of sugar water. As carbon dioxide is given off, continually raise the syringe plunger so as to keep the two columns of the manometer equal height. Continue this until gas is no longer evolved. When the gas has stopped evolving, the amount of gas trapped in the syringe will be a very accurate measure of the total amount of gas given off since use of the manometer insures that pressure in the rest of the system is maintained at the original level.

Fermentation Tube and Manometer Combination

D. MANOMETER

D1. Manometer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Stand	1	Wood (A)	75 cm x 8 cm x 2 cm
	2	Wood (B)	30 cm x 4 cm x 2 cm
	2	Wood (C)	4 cm x 4 cm x 2 cm
(2) "U" Tube	2	Glass Tubing (D)	60 cm long, 0.75 cm outside diameter, 0.5 cm inside diameter
	1	Rubber Tubing (E)	50 cm long, 0.7 cm inside diameter
	4	Fine Wire (F)	8 cm long
(3) Scale	1	Graph Paper (G)	40 cm long, 2 cm wide

b. Construction

(1) Stand

Nail two pieces of wood (B) together at right angles to form the base of the stand. Nail the square blocks (C) under the upper board to provide stability. Finally, nail the other board (A) into an upright position on the base. Drill four pairs of small holes (0.2 cm in diameter) into the upright in such a position that each pair of holes will be in line with the position of the "U" tube when it is in place.

(2) "U" Tube

Top View

Heat one of the pieces of glass tubing (D) about 4 cm from one end and bend it to a right (90°) angle. Attach the rubber tubing (E) to the end of each piece of glass tubing (D). Fasten this "U" tube to the stand upright (A) by passing the fine wires (F) around the tubing, through the holes in the upright, and twisting the wires tight to hold the tubes in place. Do not fasten the straight tube too tight in order to allow it to slide up and down to adjust the height of the indicator liquid.

(3) Scale

Glue or tape a piece of graph paper (G) between the two tubes to serve as a scale. Suitable scales can also be made by hand with plain paper and a rule.

c. Notes

(i) Use the manometer to detect and measure changes in pressure. To do so, it must be half filled with an indicator solution like colored water (use food coloring or ink) which serves as well as anything as an indicator. In normal usage, a rubber tube is used to connect the manometer to a closed system in which the pressure is changing (e.g., a jar containing a yeast-sugar solution or a jar containing a respiring animal with KOH to absorb the CO_2 given off. With the yeast solution, pressure in the jar will increase as the yeast oxidize the sugar. See VIII/C3 for further detail. In the case of the respiring animal, pressure will decrease as it takes up O_2 and gives up CO_2 which is taken up by the KOH.). As pressure changes, the indicator solution will move up or down depending on the direction of the pressure change.

(ii) A detailed, specific example of the use of the manometer is as follows:

Drill a hole in the bottom of a plastic medicine vial. This hole needs to be large enough to insert a short piece of glass tubing (5 cm long). Attach a piece of rubber tubing (100 cm) to the glass tube, and insert the glass tube into the hole in the bottom of the vial. Seal the joint with melted wax from a candle. Stretch a rubber membrane or piece of toy balloon over the open end of the vial and fasten it securely with a string or rubber band to hold the membrane on the vial.

Side View

Attach the end of the rubber tubing to the bent piece of glass tubing on the manometer "U" tube. Slide the straight tube up or down to make the height of the indicator solution the same in both tubes. Place the rubber membrane against the carotid artery of the throat. A pulse can be seen by the rythmic rise and fall of the indicator solution. (See illustration on next page.)

(iii) The manometer may be made from a single piece of glass tubing by bending it in a flame to a 180° angle. While this eliminates the need for a rubber tube, it also eliminates the possibility of adjusting the heights of the indicator solution.

(iv) Further instruction in the use of the manometer may be found in the Nuffield O-Level Biology, Teacher's Guide III, p 34, and the BSCS Blue Version text, p L8, L95, among other sources.

E. CHROMATOGRAPHY APPARATUS

E1. Chromatographic Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Test Tube	1	Test Tube (A)	15 cm long, 2 cm diameter
(2) Paper Holder	1	1-Hole Stopper (B)	To fit test tube
	1	Paper Clip (C)	--
(3) Paper	1	Filter Paper (D)	1 or 2 cm shorter than the length of the test tube
(4) Solvent	--	Acetone (E)	2 ml
	--	Petroleum Ether (F)	23 ml

b. Construction

(1) Test Tube

Use a rack or holder to support the test tube (A).

(2) Paper Holder

Open up the paper clip (C) and cut it as shown. A short piece of wire can be bent to the same shape, too. Punch the U-shaped piece of clip or wire through one end of the paper (D) and force the ends of the wire up

into the one-hole stopper (B) until it is held fast.

(3) Paper

Use standard filter paper (D) or chromatography paper if it is available. Cut it about 1.0 cm wide.

(4) Solvent

Mix the acetone (E) and petroleum ether (F) and add the mixture to the test tube.

c. Notes

(i) This chromatographic device is used to separate plant pigments. To prepare the sample of pigments, grind several heavily pigmented plant leaves together with some fine sand and about 5 ml of acetone. When thoroughly ground, filter this mixture through filter paper. Alternatively, heat several finely chopped leaves in about 5 - 10 ml of alcohol in a water bath. Do not heat the alcohol directly. Heat this mixture until the liquid is dark green.

Avoid both touching the surface of the paper with the fingers (oil affects the results) and having the paper touch the table where the pigment's to be placed. Thus, support the paper strip between two pencils or other small objects. About 1 cm from one end of the paper, place a small drop of pigment. This is most easily done with a fine-pointed pipette or a hypodermic syringe. When the first drop is dry, add another. Try to make the spot as small and as densely colored as possible. At least four drops should be placed one atop the other.

Make a notch in the paper on each side of the spot to mark its position. Attach the paper to the wire and put the wire into the stopper. Insert the paper holder in the test tube so that the end of the paper is in the solvent with the spot about 0.5 cm above the level of the liquid. It may be necessary to adjust the paper holder to keep the paper at the proper level. When the upper level of the solvent has soaked into the paper almost to the paper holder wire, remove the chromatogram and allow it to dry. The bands of color can be studied when the chromatogram is thoroughly dry. A number of excellent references exist describing additional exercizes and information for chromatography.

Finished Chromatogram

IX. MULTIPURPOSE SYRINGES

Disposable plastic syringes afford a variety of uses in biological studies. A few of these will be given in this section. Additionally, syringes can be used as pipettes, burettes, etc., and for many of the functions normally taken by test tubes. They are potentially one of the most useful items in the laboratory. All syringes in this chapter are to be used without their needles. The categories given below have been arrived at according to the function of the syringe within the system.

Readers with special interest in disposable syringes are referred to Paul D. Merrick, Experiments with Plastic Syringes, and two articles by Andrew Farmer in the School Science Review.

A. INJECTION AND EXTRACTION SYSTEMS

In these devices, disposable syringes are used for accurately injecting or extracting precise amounts of materials into or out of closed systems.

B. COLLECTION APPARATUS

Here, syringes are used to collect gases in measurable quantities.

C. REACTION CHAMBER

In this device, the syringe itself is used as the container for the reactions.

D. RESPIROMETERS

Two versions of respirometers fashioned from plastic syringes are given.

A. INJECTION AND EXTRACTION APPARATUS

A1. Diffusion Chamber ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Syringe (A)	20-35 cc
(2) Chamber	1	Glass Bottle (B)	1 liter
	1	Balloon (C)	--
	1	2-Hole Stopper (D)	--
	1	1-Hole Stopper (E)	--
	2	Glass Tubing (F)	9 cm long, 0.5 cm diameter
	2	Rubber Tubing (G)	7 cm long, 0.4 cm diameter
	2	Clamps (H)	CHEM/IV/A4 or A5

©From Andrew Farmer, "The Disposable Syringe: Additional Experiments," School Science Review, CLXXVIII (1970), 61-62.

(1) Syringe

Use the syringe (A) to inject air into the chamber.

(2) Chamber

Side View

Take the top from the glass bottle (B) and drill or punch a hole in the center of it which allows for a tight fit of the two-hole stopper (D), and then glue the stopper in place. Insert one of the glass tubes (F) into the one-hole stopper (E) so that one end of the glass tube is even with the end of the stopper. Next, insert the two glass (F) tubes into the two-hole stopper, making sure that the one with the one-hole stopper attached to it will be inside the bottle when the lid is placed on the bottle. Place the balloon (C) over the one-hole stopper and glue it into place, thus preventing a gas leakage at this end. To the two ends of the glass tubes which are to be outside of the bottle, attach the sections of rubber tubing (G). To the glass tube having the one-hole stopper on it, connect the rubber tubing to the syringe (A). Finally, place the clamps (H) over both pieces of rubber tubing.

c. Notes

(i) This apparatus is used to demonstrate the diffusion of a gas through a permeable membrane. One such experiment will be described here. It is concerned with the diffusion of carbon dioxide through a membrane. Remove the clamp from the piece of rubber tubing going to the syringe. Next, place 2 - 3 g of baking soda ($NaHCO_3$) into the syringe to which is added 8 - 10 ml of vinegar. Immediately force the mixture into the balloon using the plunges in the syringe, and then replace the clamp on the rubber tubing. Allow the apparatus to rest for 24 hours. Place the syringe on the other piece of rubber tubing, remove the clamp, and draw out some of the gas in the bottle (not in the balloon) into the syringe. This gas should contain a largc proportion of carbon dioxide. To show this, inject the gas into a solution of limewater in which a white precipitate will be formed.

(ii) Plastic tubing can be used in lieu of rubber tubing.

A2. Anesthetizing Chamber ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Chamber	1	Syringe (A)	25-50 cc
	1	Test Tube (B)	10 ml
	1	1-Hole Stopper (C)	--
	1	Clamp (D)	CHEM/IV/A4 or A5
	1	Glass Tubing (E)	5 cm long, 0.5 cm diameter
	1	Rubber Tubing (F)	3 cm long, 0.4 cm diameter

b. Construction

(1) Chamber

Insert the piece of glass tubing (E) into the one-hole stopper (C) so that a small portion of it extends out of the end to be placed in the test tube (B). Next, slide the rubber tubing (F) over the other end of the glass tube and

©From Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 8.

connect this to the syringe (A). Finally, insert the one-hole stopper into the test tube (B) and pinch the rubber tubing shut by using the clamp (D).

c. Notes

(i) This anesthetizing system can be employed in one of two ways. First, small insects can be put into the barrel of the syringe. The clamp is removed, the stopper is taken out of the test tube, and the plunger is depressed as far as possible without crushing the insects. The clamp is then replaced and a gas suitable for anesthetizing the insects (for example, carbon dioxide) is put into the test tube and the stopper is replaced into the test tube. The clamp is then removed and gas is drawn into the barrel of the syringe, anesthetizing the insects. Alternatively, the barrel of the syringe and the test tube can reverse roles.

A3. Enzymatic Reaction Chamber ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Chamber	1	Syringe (A)	25-50 cc
	1	Test Tube (B)	10 ml
	1	1-Hole Stopper (C)	--
	1	Glass Tubing (D)	5 cm long, 0.5 cm diameter
	1	Rubber Tubing (E)	3 cm long, 0.4 cm diameter

b. Construction

(1) Chamber

Insert the piece of glass tubing (D) into the one-hole stopper (C) so that a small portion of it extends out of the end to be placed in the test tube (B). Next, slide the

©From Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 19.

rubber tubing (E) over the other end of the glass tube and connect this to the syringe (A). Finally, insert the one-hole stopper into the test tube.

c. Notes

(i) To operate this piece of apparatus, remove the stopper from the test tube and place a suspension of dried yeast and water into it. Place a 3% solution of hydrogen peroxide (H_2O_2) in the syringe. Replace the stopper in the test tube and inject the hydrogen peroxide solution into the test tube. Oxygen gas is given off as a result of the reaction.

(ii) The reaction can be made quantitative by carefully noting the amount of hydrogen peroxide used.

B. COLLECTION APPARATUS

B1. Plant Gas Collection Device ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Syringe (A)	20-25 cc
	1	Beaker (B)	100-500 ml
	1	Aquatic Plant (C)	--

b. Construction

(1) Syringe

Fill the syringe (A) with water and then keep the plunger in a fixed position. Fill the beaker (B) with water. Cut a sprig from a fully leaved plant (C), for example, pondweed (elodea), and put the cut stem into the nozzle of the syringe. Finally, place the rest of the

©From Andrew Farmer, "The Disposable Syringe: Additional Experiments," School Science Review, CLXXVIII (1970), 63-64.

sprig into the beaker of water.

c. Notes

(i) The bubbles of gas given off from the stem of the plant as it carries on respiration and/or photosynthesis will be trapped in the syringe where the gas may be kept for analysis. At the end of the experiment, the water in the syringe should be boiled and allowed to cool to remove dissolved gases. Several plants may have to be used to obtain a sufficiently large amount of gas for analysis. Since photosynthesis consists of two reactions, a light reaction and a dark reaction, it would be desirable to do two experiments--one with the plants in the presence of light and one with the plants in the dark. The gases can then be analyzed to determine the differences in constitution.

B2. Seedling Gas Collection Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Syringe (A)	35-50 cc
	1	Beaker (B)	50-100 ml
	1	Rubber Tubing (C)	5 cm long, 0.4 cm diameter
	10	Day-old Bean Seedlings (D)	--

b. Construction

(1) Syringe

Fasten the rubber tubing (C) to the nozzle of the syringe (A) and place the bean seedlings (D) in the barrel of the syringe. Next, fill the beaker (B) with water and put the end of the tubing in the water to prevent gas from escaping from the syringe.

c. Notes

(i) Day-old bean seedlings carry on only respiration. Thus, the gas collected in the syringe after a period of six hours will be primarily carbon dioxide (CO_2). This can be shown by injecting the collected gas into a solution of limewater in which a white precipitate will be found. No reaction will occur if normal air is injected into the limewater. This same experiment can be done using insects.

C. REACTION CHAMBER

C1. Carbon Dioxide Production Chamber©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Chamber	1	Syringe (A)	1-10 cc
	1	Test Tube (B)	10-20 ml
	1	Small Piece of Wool (C)	--
	1	Dry Yeast (D)	0.5 g

b. Construction

(1) Chamber

Place the wool (C) loosely in the bottom of the barrel of the syringe (A) and sprinkle the dry yeast (D) over it. Replace the syringe plunger and fill the test tube (B) with a sugar and water solution.

c. Notes

(i) To operate, depress the plunger until it almost touches the yeast, insert the nozzle of the syringe into the test tube, and withdraw the plunger, thus filling the syringe with sugar water. Set the apparatus aside and check it after 24 hours. The syringe will be full of gas which can be shown to be carbon dioxide (CO_2).

©From Andrew Farmer, "The Disposable Syringe: Additional Experiments," School Science Review, CLXXVIII (1970), 64-65.

D. RESPIROMETERS

D1(1). Respirometer ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Reservoir	2	Wood (A)	10 cm x 6 cm x 0.5 cm
	2	Wood (B)	6 cm x 1.5 cm x 0.5 cm
	1	Wood (C)	10 cm x 2.5 cm x 0.5 cm
	2	Stiff Plastic Tubing (D)	3 cm long, 0.4 cm diameter
(2) Body	1	Wood (E)	30 cm x 10 cm x 2 cm
	1	Wood (F)	10 cm x 6 cm x 0.5 cm
	2	Syringes (G)	25-35 cc
	2	Flexible, Clear Plastic Tubing (H)	30 cm long, 0.5 cm diameter

©From Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 11.

b. Construction

(1) Reservoir

Front View of
Wood (A)

In one of the pieces of wood (A), drill two holes 0.4 cm in diameter into which the two pieces of stiff plastic tubing (D) are to be glued so that they stick out equally on each side of the wood.

Glue the two longer pieces of wood (A) to the base (C), and then glue the narrow pieces (B) between the base and sides. Be sure to use a waterproof glue. Coat the inside of the reservoir with either waterproof glue or paint.

(2) Body

Front View of
Wood (F)

Into one piece of wood (F), drill two holes slightly larger in diameter than the syringes (G) used. Nail this piece to the base (E). Glue the reservoir to the other end of the base with the plastic tubes (D) facing the wood piece (F). Put both syringes (G) through their holes and attach the syringe nozzles to the plastic outlets of the reservoir with the clear tubing (H). The syringes may

be glued in position if desired.

c. Notes

(i) This apparatus can be used to study the respiration rates of small animals and plants. One syringe serves as a control and the other as a chamber for the animals or plants (e.g., flies, seedlings). Into each syringe, put a small container of powdered or liquid lye (NaOH or KOH) to absorb carbon dioxide. At the beginning of the experiment, draw some of the water in the reservoir into the tubes so that the two water columns are the same length. If the syringe plungers are put at the same position, then the volumes of each system will be the same to begin the experiment. As the organisms in one syringe respire, carbon dioxide will be given off and taken up by the lye. This will cause a change in the pressure of the air in the syringe and thus, cause a change in the relative lengths of the water columns. Varying the diameter of the plastic tubes will cause the changes to be faster or slower depending on whether the diameter is decreased or increased, respectively.

D1(2). Respirometer ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Reservoir	1	Wood (A)	15.2 cm x 12 cm x 0.6 cm
	2	Wood (B)	12 cm x 6 cm x 0.6 cm
	2	Wood (C)	10 cm x 6 cm x 0.6 cm
	2	Wood (D)	6 cm x 4 cm x 0.6 cm
	1	Wood (E)	6 cm x 3 cm x 0.6 cm
	2	Stiff Plastic Tubing (F)	3 cm long, 0.4 cm diameter
(2) Syringes	2	Syringes (G)	25-35 cc
	2	Flexible, Clear plastic Tubing (H)	15 cm long, 0.5 cm diameter
	1	Waterproof Paper (I)	11 cm x 0.5 cm

©From Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 31.

b. Construction

(1) Reservoir

Base (A)

Cut the base (A) as shown in the drawing. Take one of the pieces of wood (B) and drill two holes equal in diameter to the diameter of the barrels of the syringes (G) being used. In addition, drill two holes 0.4 cm in diameter for the two pieces of stiff plastic tubing (F). Take this piece of wood and, using waterproof glue, attach it to the end of the base having the wood projection. Next, glue the two sides (C) in place.

End Piece (B)

End Piece (C)

Drill two holes in the other piece of wood (B) equal in diameter to the nozzle of the syringes (G), and two holes equal in diameter to that of the flexible plastic tubing (H).

Secure this piece of wood in place using waterproof glue. Using the three pieces of wood (D,E) and waterproof glue, form a reservoir against the end of the box using the wood projection as a base. Paint the inside of the entire apparatus using an oil base paint in order to prevent the wood from warping.

(2) Syringes

Glue the syringes (G) in the holes made for them and attach the flexible, clear plastic tubing (H) as shown. Finally, seal either all inside or outside seams with waterproof glue. If so desired, a scale (I) may be placed between the two pieces of flexible tubing to measure the relative movement of water in the two tubes.

c. Notes

(i) Place the respiring organism in one syringe along with a small container of sodium hydroxide (NaOH, to absorb carbon dioxide), and place a similar container of sodium hydroxide in the other syringe along with some inert material to compensate for the volume of the organism. When the apparatus has been correctly set up, fill the small reservoir with colored water (use a non-fast dye), and fill the main reservoir with room-temperature water to serve as insulation. Setting

both syringes at the same volume should cause water to be drawn from the small reservoir into the plastic tubing to the same mark on the scale. As the organism respires, more water will be drawn from the reservoir (the dye allows it to be easily seen), and the change will be measurable.

If desirable, the piston of the syringe containing the organism may be depressed to reset the water level in the tubing.

(ii) The advantage of this respirometer over the previous one described is that with this apparatus, the water both keeps the syringes and the water in the plastic tubing at the same temperature thus eliminating the possibility of temperature variation between one syringe and the other which in turn might cause a difference in respiration rates.

BIBLIOGRAPHY

A number of texts have proved to be extremely valuable references to the Inexpensive Science Teaching Equipment Project, and these are listed below.

American Peace Corps, Science Teachers Handbook, (Hyderabad, India: American Peace Corps, 1968).

This handbook contains many ideas for improvising science teaching equipment.

Association for Science Education, The School Science Review, (London: John Murray).

A quarterly journal containing articles on science experiments and equipment in all the sciences at all school levels.

Association for Science Education, The Science Master's Book, (London: John Murray).

Part 2 of Series 1 and 2, and Part 3 of Series 3 and 4 of The Science Master's Book contain articles from The School Science Review dealing with experiments and equipment in biology.

Knudsen, Jens W., Biological Techniques, (New York: Harper and Row, 1966).

An excellent reference for those persons interested in collecting, preserving, and illustrating animals and plants.

Merrick, Paul D., Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968).

This book and accompanying materials form a good basis for developing curriculum materials based on disposable plastic syringes.

Morholt, Evelyn, Paul F. Brandwein, and Alexander Joseph, A Sourcebook for the Biological Sciences, (New York: Harcourt Brace, and World, 1966).

This book gives many ideas and methods concerned with the day-to-day teaching of biology.

The UNESCO Sourcebook in Science Teaching, (Paris, France: UNESCO, 1972).

This book, recently revised, contains many simple ideas for teaching science at a relatively elementary level.

In addition to the above texts, the materials from a large number of projects in the files of the International Clearinghouse on Science and Mathematics Curricular Developments at the University of Maryland have also been particularly valuable. Further details of these projects, and the three listed below, may be found in:

The Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments 1970, (College Park, Maryland: University of Maryland, 1970).

This is a source of information on curriculum projects throughout the world including project director, materials available, publishers, etc. The Eighth Report will be available in late 1972.

Biological Sciences Curriculum Study (BSCS).

This is the major United States project concerned with the biological sciences at the secondary level. One publication, Innovations in Equipment and Techniques in the Biology Teaching Laboratory, (Boston: D. C. Heath, 1964) is especially useful to those interested in equipment development.

FUNBEC, Science Education Projects for Primary, High School and College Level.

A Brazilian project, FUNBEC has developed an excellent series of inexpensive science kits including some dealing with biology.

Nuffield Foundation, Nuffield Biology.

The Nuffield projects are the major British curriculum projects in science. Expecially interesting to the secondary biology teacher and administrator are the "O-level" and "A-level" material.

GUIDEBOOK TO CONSTRUCTING INEXPENSIVE SCIENCE TEACHING EQUIPMENT

Volume II: Chemistry

Inexpensive Science Teaching Equipment Project
Science Teaching Center
University of Maryland, College Park
U. S. A.

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FOREWORD

History

The Inexpensive Science Teaching Equipment Project was initiated by Dr. J. David Lockard, and got underway under his direction in the summer of 1968. Originally entitled the Study of Inexpensive Science Teaching Equipment Worldwide (IS-TEW or IS-2 Study), the Project was to (1) identify laboratory equipment considered essential for student investigations in introductory biology, chemistry and physics courses in developing countries; (2) improvise, wherever possible, equivalent inexpensive science teaching equipment; and (3) produce designs of this equipment in a Guidebook for use in developing countries. Financial support was provided by the U.S. Agency for International Development through the National Science Foundation.

The initial work of the Project was undertaken by Maria Penny and Mary Harbeck under the guidance of Dr. Lockard. Their major concern was the identification of equipment considered basic to the teaching of the sciences at an introductory level. An international survey was conducted, and a list of equipment to be made was compiled. A start was also made on the writing of guidelines (theoretical designs) for the construction of equipment.

Work on the development of the Guidebook itself got underway in 1970, with the arrival of Reginald F. Melton to coordinate the work. Over 200 guidelines were completed during the year by Donald Urbancic (Biology), Chada Samba Siva Rao and John Delaini (Chemistry), and Reginald Melton (Physics). Full use was made of project materials from around the world which were available in the files of the International Clearinghouse on Science and Mathematics Curricular Developments, which is located in the Science Teaching Center of the University of Maryland. The guidelines were compiled into a draft edition of the Guidebook which was circulated in September, 1971, to some 80 science educators around the world for their comments and advice.

The work of constructing and developing equipment from the guidelines, with the subsequent production of detailed designs, began in a limited way in 1970, the major input at that time being in the field of chemistry by Chada Samba Siva Rao, who was with the project for an intensive two-month period. However, the main work of developing detailed designs from the guidelines was undertaken between 1971 and 1972 by John Delaini (Biology), Ruth Ann Butler (Chemistry) and Reginald Melton (Physics). Technical assistance was given by student helpers, with a special contribution from David Clark, who was with the project for a period of 18 months.

Thanks are due to those graduates, particularly Samuel Genova, Melvin Soboleski and Irven Spear, who undertook the development of specific items of equipment while studying at the Center on an Academic Year Institute program; to student helpers, especially Don Kallgren, Frank Cathell and Theodore Mannekin, who constructed the equipment; and to Dolores Aluise and Gail Kuehnle who typed the manuscripts.

Last, but not least, special acknowledgement is due to those individuals, and organizations, around the world who responded so willingly to the questionnaires in 1968 and to the draft edition of the Guidebook in 1971.

The Guidebook

The designs presented in the Guidebook are based on the premise that many students and teachers in developing countries will wish to make equipment for themselves. This does not mean that students and teachers are expected to produce all their own apparatus requirements. It is recognized that teachers have specific curricula to follow, and that "class hours" available for such work are very limited. It is also recognized that teachers, particularly those in developing countries, are not well paid, and often augment their salaries with supporting jobs, thus placing severe limits on the "out-of-class hours" that are available for apparatus production.

However, in designing equipment for production by students and teachers, two factors have been kept in mind. One, project work in apparatus development can be extremely rewarding for students, bringing both students and teachers into close contact with the realities of science, and relating science and technology in the simplest of ways. Two, it is not difficult for cottage (or small scale) industries to adapt these designs to their own requirements. The Guidebook should therefore not only be of value to students and teachers, but also to cottage industries which may well be the major producers of equipment for schools.

Although all the designs in the Guidebook have been tested under laboratory conditions in the University of Maryland, they have not been tested in school situations nor produced and tested under local conditions in developing countries. It is therefore recommended that the designs should be treated primarily as limited resource materials to be subjected to trial and feedback. It is suggested that the first time that an item is constructed it should be made precisely as described in the Guidebook, since variations in the materials, or the dimensions of the materials, could alter the characteristics of the apparatus. However, once this item has been tested the producer is encouraged to make any number of modifications in the design, evaluating the new products against the original.

Before producing new equipment in quantity, it is recommended that educators with experience in the field of science education should be involved in determining how best to make use of the Guidebook. They will wish to relate the apparatus to their own curriculum requirements, and, where necessary, prepare relevant descriptions of experiments which they recommend should be undertaken using the selected apparatus. They will want to subject the experiments and related equipment to trials in school situations. Only then will they consider large-scale production of apparatus from the designs in the Guidebook. At this stage educators will wish to control the quality of apparatus production, to train teachers to make the best use of the new apparatus, and to insure that adequate laboratory conditions are developed to permit full utilization of the apparatus. Too often in the past apparatus has sat unused on many a classroom shelf, simply because the teacher has been untrained in its usage, or the laboratory facilities have been inadequate, or because the apparatus available did not appear to fit the requirements of the existing curriculum. Such factors are best controlled by educators in the field of science education in each country. Clearly the science educator has a crucial role to play.

Apparatus development, like any aspect of curriculum development, should be considered as a never ending process. This Guidebook is not presented as a finished product, but as a part of this continuing process. There is no doubt that the designs in this book could usefully be extended, descriptions of experiments utilizing the apparatus could be added, and the designs themselves could be improved. No extravagant claims are made concerning the Guidebook. It is simply hoped that it will contribute to the continuing process of development.

TOOLS AND RAW MATERIALS

The raw materials required to make specific items of equipment are indicated at the beginning of each item description. However, there are certain tools and materials which are useful in any equipment construction workshop, and these are listed below.

Tools

Chisels, Wood

3, 6, 12, 24 mm
(i.e., 1/8", 1/4", 1/2", 1")

Cutters

Bench Shears: 3 mm (1/8") capacity
Glass Cutter
Knife
Razor Blades
Scissors: 200 mm (8")
Snips (Tinmans), Straight: 200 mm (8")
Snips (Tinmans), Curved: 200 mm (8")
Taps and Dies: 3 to 12 mm (1/8" to 1/2") set

Drills and Borers

Cork Borer Set
Countersink, 90°
Metal Drill Holder (Electrically Driven), Capacity 6 mm (1/4")
Metal Drills: 0.5, 1, 2, 3, 4, 5, 6, 7 mm
(i.e., 1/32", 1/16", 3/32", 1/8", 5/32", 3/16", 7/32", 1/4") set
Wood Brace with Ratchet: 250 mm (10")
Wood Augur, Bits: 6, 12, 18, 24 mm
(i.e., 1/4", 1/2", 3/4", 1")

Files, Double Cut

Flat: 100 mm, 200 mm (4", 8")
Round: 100 mm, 200 mm (4", 8")
Triangular: 10C mm (4")

Hammers

Ball Pein: 125, 250, (1/4, 1/2 lb)
Claw 250 g (1/2 lb)

Measuring Aids

Caliper, Inside
Caliper, Outside
Caliper, Vernier (may replace above two items)
Dividers: 150 mm (6"), Toolmakers
Meter, Electrical (Multipurpose - volts, ohms, amps, etc.)
Meter Stick
Protractor
Scriber

Measuring Aids (Continued)

Set Square
Square, Carpenter's: 300 mm (12") blade
Spoke Shave: 18 mm (3/4")
Wood Smoothing Plane

Pliers

Combination: 150 mm (6")
Needle Nose: 150 mm (6")
Side Cutting: 150 mm (6")
Vise Grips

Saws, Metal

300 mm (12") blades

Saws, Wood

Back Saw: 200, 300 mm (8", 12")
Coping Saw: 200 mm (8")
Cross Cut: 600 mm (24")
Hand Rip: 600 mm (24")
Key Hole Saw: 200 mm (8")

Screw Drivers

100 mm (4"), with 2 and 3 mm tips
150 mm (6"), with 5 mm tip
200 mm (8"), with 7 mm tip

Vises

Metal Bench Vise: 75 mm (3")
Wood Bench Vise: 150 mm (6")

Miscellaneous

Asbestos Pads
Goggles, Glass
Oil Can: 1/2 liter (1 pint)
Oil Stone, Double Faced
Punch, Center
Sandpaper and Carborundum Paper, Assorted grades
Soldering Iron: 60 watts, 100 watts

Raw Materials

Adhesives

All Purpose Cement (Elmers, Duco)
Epoxy Resin & Hardener (Araldite)
Rubber Cement (Rugy)
Wood Glue (Weldwood)
Cellophane Tape
Plastic Tape
Masking Tape

Electrical Materials

Bulbs with Holders: 1.2, 2.5, 6.2 volts
Dry Cells: 1.5, 6 volts
Electrical Wire: Cotton or Plastic covered
Fuse Wire: Assorted
Lamps: 50, 75, 100 watts
*Magnet Wire: #20, 22, 24, 26, 28, 30, 32, 34
Nichrome Wire: Assorted
Parallel Electrical Cording
Plugs
Switches

Glass and Plastic

Acrylic (Plastic) Sheets: 2 cm and 2.5 cm thick
Plates, Glass
Tubes, Glass: 3, 6 mm (1/8", 1/4") internal diameter

Hardware

Bolts and Nuts, Brass or Steel; 3 mm (1/8") diameter: 12, 24, 48 mm (1/2", 1", 2") lengths
Nails: 12, 24 mm (1/2", 1") lengths
Screws, Eye
Screws, Wood: 12, 18, 24, 26 mm (1/2", 3/4", 1", 1 1/2") lengths
Thumbtacks
Washers (Brass and Steel): 6, 9 mm (1/4", 5/16") diameter
Wingnuts (Steel): 5 mm (3/16")

Lumber

Boxwood (Packing Case Material)
Hardboard: 6 mm (1/4") thick
Kiln Dried Wood: 2.5 x 15 cm (1" x 6") cross section
1.2 x 15 cm (1/2" x 6") cross section
Plywood: 6, 12 mm (1/4", 1/2") thickness
Wood Dowels: 6, 12 mm (1/4", 1/2") thickness

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* U. S. Standard Plate numbers are used in this book to indicate the gauge of different wires. Where wires are referenced against other numbering systems appropriate corrections should be made in determining the gauges of materials required. The following comparison of gauges may be of interest:

Standard	Diameter of #20 Wire
Brown & Sharp	0.08118
Birmingham or Stubs	0.089
Washburn & Moen	0.0884
Imperial or British Standard	0.0914
Stubs' Steel	0.409
U. S. Standard Plate	0.09525

Metal Sheets

Aluminum: 0.2, 0.4 mm (1/100", 1/64") thickness.
Brass: 0.4, 0.8 mm (1/64", 1/32") thickness.
Galvanized Iron: 0.4 mm (1/64") thickness.
Lead: 0.1 mm (1/250") thickness.
Spring Steel, Packing Case Bands

Metal Tubes:

Aluminum, Brass, Copper: 6, 12 mm (1/4", 1/2") internal diameter.

Metal Wires

Aluminum: 3 mm (1/8") diameter
Coathanger: 2 mm (1/16") diameter
*Copper: #20, 24
Galvanized Iron: 2 mm (1/16") diameter
*Steel: #20, 26, 30.

Paint Materials

Paint Brushes
Paint Thinner
Varnish
Wood Filler

Miscellaneous

Aluminum Foil
Cardboard Sheeting
Containers (Plastic or Glass)
Corks (Rubber or Cork)
Grease
Hinges: Assorted
Machine Oil
Marbles
Mesh (Cotton, Nylon, Wire)
Modelling Clay (Plasticene)
Paper Clips
Pens: Felt (Marking Pens)
Pins and Needles
Rubber Bands
Soldering Lead
Soldering Paste
Spools
Steel Wool
Straws
String (Cord, Cotton, Nylon)
Styrofoam
Syringes: Assorted
Wax (Paraffin)

*See footnote on previous page.

I. GLASSWARE TECHNIQUES AND ACCESSORIES

Equipment made of glass or using glass components has applications in all branches of science. This chapter includes some basic glass-working techniques that will be necessary for constructing much of the equipment in this book.

These are presented in sections which describe the type of equipment needed, the type of glass to use, and techniques for working with several forms of glass.

A. BURNERS, TOOLS, AND EQUIPMENT

This section discusses burners that can be used in working glass, as well as listing the tools and other items necessary for working with glass.

B. GLASS

This section describes the type of glass that works best with the burners listed in section A.

C. SAFETY

Notes for safe handling and working of glass are given here.

D. PROCEDURES FOR GLASS TUBING AND RODS

Directions for working with glass tubing and solid rods are given in this section.

E. GLASS SHEET OPERATIONS

This section tells how to cut and drill glass sheets.

F. BOTTLE AND JAR TECHNIQUES

Much useful laboratory glassware can be made by using discarded bottles and jars. This section includes directions for cutting and drilling these items.

G. STOPPERS

This section discusses types of stoppers and describes techniques for drilling holes in them.

A. BURNERS, TOOLS, AND EQUIPMENT

Glass-working techniques described here are designated for use with Modified Alcohol Burner (II/B2), and the Gas Burner (II/C2). Of these, the gas burner, if available, is most highly recommended.

The general items required for general glass-working techniques are as follows:

Glass Cutter

Triangular File

Round File

Set of Cork-borers

Pliers

Brick or Asbestos Pads

Rags or Pieces of Cloth

Clean rags, or pieces of cloth no smaller than about 10 cm x 10 cm.

String

Kerosene

Camphor

Ruler

Blotting Paper or Paper Towels

Emery Paper

Container of Sand

B. GLASS

There are many different types of glass, with different properties, depending upon the chemical composition of the glass. Two very common types of glass that are discussed here are "soft glass" and "hard glass."

Soft Glass

This term includes a number of the oldest known and most common types of glass in general use. Most bottles, jars, window glass, and much glass tubing and rods are made of some type of soft glass. Such glass is used for items of simple design and moderate thickness, that will not be subjected to very high temperatures.

One of the most important properties of soft glass, from the point of view of this book, is that it can be softened in the heat of an air-gas flame. This is the type of flame produced by the burners specified in section A. Also, soft glass has a wide range of working temperatures, which makes it easy to work even after it has been removed from flame.

Although it is easy to work, soft glass has some limitations and must be used with care. An empty container of soft glass cannot be greatly heated, or it will crack. If, however, such a container holds a liquid or powder, it can safely be heated, slowly. Also, a soft glass container, with or without anything inside, must not be suddenly cooled when hot or suddenly heated when it is cold. Otherwise, it will break.

Hard Glass

Hard glass has been developed during the twentieth century. Of a number of types produced, "Pyrex" is one of the most common brand names. Most manufactured laboratory glassware is now made of hard glass, which is harder, stronger, more chemically inert, and safer to use over a wider temperature range than soft glass.

Laboratory glassware made of hard glass is safer than soft glass. It can be rapidly heated or cooled to greater temperature extremes without danger of breaking. It does not scratch easily, and it does not break as easily as soft glass if struck or dropped.

Although it is often manufactured into laboratory glassware, hard glass is not generally made into the bottles and jars that are used for much of the apparatus described in this book. Therefore, it is not as generally available as soft glass. As tubing, rods, and sheets, it is usually more expensive than the same items made of soft glass.

Hard glass's most important disadvantage here is that it must be worked in an oxygen-enriched flame. The burners described in section A cannot heat hard glass hot enough for working.

Therefore, only soft glass is suitable for use with the alcohol or gas burners

described. The techniques here listed have been tested using soft glass and the air-gas flames produced by such burners.

Testing for Soft Glass

To determine whether a piece of glass is "hard glass" or "soft glass", heat it in the flame of an alcohol or gas burner. If the glass begins to glow and soften enough to be easily worked, it is soft glass. If it does not soften, it is hard glass and cannot be worked without specialized equipment.

C. SAFETY

Glass working, like most other laboratory procedures, carries a set of risks. By arranging a safe work area and taking a few precautions, however, most such risks can be avoided.

Sharp Edges and Points

There is always a danger of being cut by sharp points and edges of broken or cut glass. Be careful of such edges and points, and try to handle the glass away from the edges. Fire polish or smooth with emery paper any cut edges or points that are part of a finished project. Keep such edges away from the mouth and eyes at all times, and keep the work area clear of waste glass.

Burns

Hot glass looks just like cool glass! To avoid burns, allow heated glass to cool before handling it. Rest it on bricks or asbestos pads, or in a container of sand. Before picking up a piece of previously heated glass, touch it lightly with the fingertips to check that it is cool enough to handle. In cases where hot or warm glass must be handled, protect the hands with a holder of several layers of cloth, or use holders such as those described in the section on holders (IV). Protect the body from burns with clothing, an apron, overall, or laboratory coat.

Fire

Both the burner flame and hot glass can start a fire. Prevent this by keeping all flammable material, such as paper or cloth away from the flame and any hot glass. Set hot glass down on things that will not burn, such as bricks, asbestos pads, or sand. To keep hair or clothing from being singed or igniting, tie back long hair, roll up sleeves, and secure loose clothing close to the body. Inspect the burner, fittings, tubing, and fuel supply each time the equipment is used to prevent leaks of fuel that might lead to a fire. If any alcohol should spill, immediately put out the flame and mop up the spill.

The container of sand mentioned for holding hot glass is also useful for fire control. If paper, cloth, or spilled alcohol should ignite, smother the fire by dumping sand on it. If, on the other hand, the gas burner system (II/C1) is used and a fire develops, get away fast!

Eye Damage

To prevent eye damage, keep all sharp edges and points, all hot glass, and all flames away from the eyes. Wear safety goggles or eye glasses to provide additional protection for the eyes.

Gas Danger

If natural gas or bottled gas is used as fuel for the burner, a leak in the system can release gas that is poisonous to breathe. To avoid this danger, inspect all pipes, tubing, and fittings often.

D. PROCEDURES FOR GLASS TUBING AND RODS

D1. Cutting

a. Materials Required

Length of soft glass tubing or solid rod

Triangular file

Ruler

b. Procedure

Lay the tubing or rod flat on the work surface and measure the desired length. Make a scratch on the glass at this point by drawing one edge of the file across the tube. Press hard enough with the file to make a deep scratch.

Moisten the scratch, then grasp the glass firmly in both hands with the thumbs on the side of the tube opposite the scratch. Apply pressure with the thumbs while pulling out and down with the hands until the tube or rod snaps cleanly.

D2. Bending

a. Materials Required

Burner: wide-flame alcohol burner

or

wing tip with gas burner

Length of soft glass tubing or solid rod

Cooling surface: brick

or

asbestos pad

b. Procedure

Gravity Bending

With one hand, hold the tubing or rod, just above the inner cone of the flame. Rotate the tubing to heat it evenly until the free end droops under its own weight.

Remove the glass from the flame. It should bend to a right angle. Allow it to cool.

Manual Bending

Install the wing tip on the gas burner, and light the burner. Hold each end of the tubing or rod. Support the glass so that it is level, with its middle in the hottest part of the flame. Turn the tubing or rod back and forth by rotating the thumb and first finger. Continue to heat it evenly until it softens.

When the tubing or rod is soft, remove it from the flame. Immediately, bend the ends up until the tubing or rod is bent at a right angle (90°).

Rest the hot tubing or rod on a brick or other cooling surface.

c. Notes

(i) If a wing tip is not available, or if a standard alcohol burner is used, the tubing or rod must be heated differently. Hold each end of the glass and support it so that it is level, with the middle just above the inner core of flame. Rotate the tubing back and forth. At the same time, move it to the left and right so that about 0.3 cm of its length of evenly heated. Continue to both rotate and move the tubing or rod until the heated section softens. Remove from the flame and bend it as described above.

(ii) With a little practice with glass tubing, you should be able to achieve a bend in which the opening stays the same throughout the bend. Overheating or underheating the tubing, however, will produce poor bends. Underheating causes the tube to fold in at the bend. Overheating causes the tube to collapse at the bend.

(iii) If a U-shaped bend is desired, first make one 90° bend as described above. After allowing the glass to cool, make another 90° bend near the first one.

D3. Stretching

a. Materials Required

Burner: wide-flame alcohol burner

or

wing tip with gas burner

Length of soft glass tubing or rod

b. Procedure

Hold the glass tubing or rod in the flame. Turn it as it heats, just as for making a bend. Heat the glass evenly until it softens. When the tubing or rod is soft, remove it from the flame. Pull the ends apart until the center has become narrow and stretched about 25 - 30 cm.

After the stretched part has cooled, it can be cut as required (I/D1). Carefully fire polish the edges (I/D4).

c. Notes

(i) Stretched glass tubing has many applications in laboratory glassware. For example, the ends of the stretched tubing pictured above, with a narrow opening at one end, may be used as nozzles or jets.

The very narrow section of the tubing, the stretched part, may be used as a capillary tube.

(ii) If a wing tip or wide-flame burner is not available, follow the procedure given for heating a wide area of glass without the wing tip [I/D2, Note (i)].

D4. Fire Polishing Tubing

a. Materials Required

Glass tubing with cut edge

Burner

Cooling surface

b. Procedure

Hold the rough, cut end of the glass tubing in the hottest part of the flame, just above the inner cone. Turn the tubing constantly until the edge glows red.

Remove the tubing from the flame. Examine the heated end. If it is now rounded smoothly, rest the hot tubing on a brick, asbestos pad, or sand to cool. If the other end of the tubing is also rough, repeat the fire polishing procedure.

c. Notes

(i) Do not overheat the end of the tubing, or it will tend to close entirely.

(ii) Fire polish the ends of all glass tubing in use, as a safety measure.

(iii) Tubing with thick walls--for example, 0.5 cm (inside diameter) and larger--must be annealed to prevent cracking. To do this, hold the end in the flame for about one second, then remove from the flame for about one second. Repeat this procedure eight or ten times, then hold the end in the flame, turning it constantly until it is red hot. To cool thick-walled tubing slowly, remove it from the flame, but hold the tubing near the flame for a few seconds. Gradually move the hot end of the tubing further from the flame until it can be rested on the brick or other cooling surface.

D5. Closing Tubing

a. Materials Required

Burner

Glass tubing

Cooling surface

b. Procedure

Narrow Tubing

When using tubing with a diameter of less than 1.0 cm, hold the end of the tubing in the hottest part of the flame, just as for fire polishing. Turn the tubing constantly. Continue heating until the end closes.

Wide Tubing

When using tubing with a diameter greater than 1.0 cm, heat the tubing near one end, rotating the tubing as it heats. When the tubing is soft, pull it apart.

Continue to heat and pull the ends apart until the ends separate and the pointed end has closed.

D6. Glass Blowing

a. Materials Required

Gas burner

Length of soft glass tubing

Cooling surface

b. Procedure

Fire polish one end of the tubing. Allow it to cool. Close the other end by heating in the flame. Heat the closed end, rotating it constantly. While continuing to heat and rotate the tube, blow very gently, in short, light puffs, into the open end of the tube. Just as the closed end of the tube begins to swell and glow pale red, remove it from the flame. Blow strongly into the tube, while rotating it, to form a small round bulb.

c. Notes

(i) This procedure takes practice and patience to learn. It is helpful to begin with the narrowest tubing available; 0.3 cm tubing, for example. A common problem is blowing out the side of the bulb while the tubing is still in the flame.

(ii) A limiting factor in the size of tubing that can be used and the size of the bulb that can be blown is the burner used. The gas generating system (II/C1) and burner (II/C2) are adequate to allow 0.3 cm and 0.5 cm tubing to be blown into bulbs about 0.8 cm in diameter.

D7. Making Rim in Tubing

a. Materials Required

Burner

Glass tubing

Triangular file

Brick, or asbestos pad

b. Procedure

Flattening

Hold one end of the tubing in the hottest part of the flame. Turn it constantly until the edge glows red. Remove the tubing from the flame. Quickly push the hot end evenly down against the brick or asbestos pad. A lip should form. Allow the glass to cool.

Flaring

Heat one end of the tubing until it is red hot. Remove the tubing from the flame. Hold the thin handle end of the file inside the end. Press gently outward on the file, while turning the tube to form a flared edge.
Allow the glass to cool.

D8. Finishing Ends of Rods

a. Materials Required

Soft glass rods

Burner

Brick, or asbestos pad

Pliers

b. Procedure

Fire Polishing

Follow the procedure for fire polishing glass tubing (I/D4). It will be necessary to heat the end of the rod for a longer period of time. The fire polished end will have a small, solid bulb. Holding the rod in the flame for a longer time will produce a larger bulb at the end.
Allow the rod to cool.

Flattening

Follow the procedure for flattening glass tubing (I/D7) to form a flat disc at the end. Allow the rod to cool.

Squeezing

Heat one end of a rod as before. When it is hot, remove it from the flame. Compress about 1 cm of the end of the rod between the jaws of the pliers. A flattened paddle-shaped end will form.
Allow the rod to cool.

c. Notes

(i) A useful stirring rod can be made with a rod of about 0.3 - 0.5 cm diameter, 15 - 20 cm long. Flatten one end and squeeze or fire polish the other.

E. GLASS SHEET OPERATIONS

E1. Cutting

a. Materials Required

Glass cutter

Sheet of glass
(for example, a pane of window glass)

b. Procedure

Lay the glass flat on bench of table. Hold the ruler along the line to be cut, with one hand; and with the other hand, draw the wheel of the glass cutter on the glass along the ruler. Press hard enough to scratch the glass.

Place the underside of the scratch exactly over the edge of the table or bench. Press down on both sides to break the glass cleanly along the scratch.

E2. Drilling a Hole

a. Materials Required

Sheet of glass

Triangular file

Hammer

Turpentine

Camphor

b. Procedure

Take a little turpentine in a bottle cap. Put a small amount of camphor in it. Chip off the end of the triangular file with a hammer. This chipped end has sharp corners.

Place the glass flat on a table. Dip one of the sharp corners of the broken file into the turpentine-camphor mixture.

Press this corner of the file down on the spot to be drilled. Twist the file back and forth to drill into the glass. Use more turpentine-camphor as needed and continue drilling until the hole is complete.

c. Notes

(i) Drilling by hand is slow and may take ten or fifteen minutes.

(ii) A completed hole can be enlarged with the edge of the triangular file or a round file, and the turpentine-camphor mixture.

(iii) After making the beginning hole on the surface of the glass, it is in fact easier to use a hand drill with the triangular file as the bit. However, extreme care must be taken. Do not push down on the drill at all, or the glass might break. Let only the weight of the drill be the force on the glass.

(iv) Follow this same procedure to drill a hole in a glass bottle or jar.

F. BOTTLE AND JAR TECHNIQUES

F1. Etching

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Etching Guide	1	Wood (A)	Approximately 10 cm x 20 cm x 1 cm
	1	Wood (B)	Approximately 10 cm x 10 cm x 1 cm

b. Construction

(1) Etching Guide

Cut V-shaped notches into one edge of a wooden board (A). Make the notches about 1 cm deep and about 2 cm (or other desired interval) apart. Then secure the base (B) at right angles to (A) with nails or glue and screws.

c. Notes

(i) The etching guide is used in combination with a triangular file or glass cutter to scratch a continuous line on a bottle or jar, prior to cutting. The

bottle or jar is placed on the stand and a glass cutter or triangular file is placed in a notch at the desired height. The bottle is rotated, and pressure is maintained against it with the tool so that a continuous scratch is scored around it.

(ii) A second method for etching a bottle, jar, light bulb, etc. to be cut is to wrap a strip of adhesive tape or paper around the glass as a guide. After the line has been scratched completely around the glass, the tape is removed.

(iii) After the glass has been etched in either of these two fashions, it may be cut using one of the techniques described in the following section.

F2. Cutting

Electrical Heating

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Stand	1	Wood (A)	30 cm x 10 cm x 2 cm
	2	Wood (B)	25 cm x 4 cm x 2 cm
(2) Terminal	2	Bolts (C)	3 cm long, 0.5 cm diameter
	4	Nuts (D)	0.5 cm
(3) Wiring	1	Nichrome Wire (E)	Size #24 (0.06 cm diameter), 34 cm long
	2	Insulated Copper Wire (F)	Size #20 (0.08 cm diameter), 125 cm long

b. Construction

(1) Stand

Drill a hole in one end of each of the two uprights (B). This hole should be slightly smaller in diameter than the bolts (C) used for the terminals. Next, nail or screw the uprights to the base (A).

(2) Terminal

Cut the heads off the two bolts (C), and put glue into the holes in the uprights (B). Screw the bolts down into the hole, leaving about 1.5 - 2 cm protruding. Next, secure the bolts by screwing on one nut (D) until it is tight. Screw on the second nut (D) loosely.

(3) Wiring

Wrap one end of the #24 nichrome wire (E) around one bolt (C) for one or two turns and do the same with the other end. Tighten the second nut (D) on the terminals until the nichrome wire is firmly held. There should be about a 5 cm sag in the middle. Fasten the copper wires (F) to each terminal in the same manner. Connect clips to these wires. For power use a transformer (PHYS/VII/A2) wired to a wall outlet [Note (iii)], or a heavy-duty battery.

c. Notes

(i) Prepare the jar, bottle, light bulb, etc., to be cut by etching a continuous line around the glass (I/F1). Connect the cutter to a power supply until the wire is hot, then place the etched line on the hot wire. Hold the glass in this position until it cracks along the healed portion. Then rotate the glass to heat another portion of the etched line. Continue this procedure until the crack has

circled the glass and the two sections separate.

(ii) The broken edges of the glass can be smoothed by rubbing them with wire gauze or wet sandpaper (emery paper).

(iii) If the wire cutter is used with a wall outlet (120 volt) then a transformer must be employed to bring the voltage down to 12 volts, 3 amps. The cutter can also be used with a standard 12 volt automobile battery. However, using a battery requires more time for heating the ètched line, since the wire does not get as hot.

String Heating

a. Materials Required

Bottle, jar, or light bulb

String

Container of cold water

Alcohol, kerosene, or turpentine

Tape or paper

Glass cutter or triangular file

b. Procedure

Prepare the bottle or jar as described in I/F1 above. After the paper or tape guide has been removed, tie a piece of string or cord which has been soaked in a flammable liquid around the bottle about 0.5 cm below the scratch. Light the string with a match, and as soon as the flame dies down, pour cold water on the bottle. The sudden change from hot to cold will break the bottle along the scratch. This process may have to be repeated to break thick glass. Smooth the cut edge of the glass as described in Note (ii) above.

Wet Paper Cooling

a. Materials Required

Bottle, jar or light bulb

Alcohol or gas burner, or candle

Triangular file or glass cutter

Blotting paper or wrapping paper

String

Container of cold water

b. Procedure

Wind a strip of blotting paper, paper towel, or wrapping paper about 5 cm wide around the bottle at one side of the line to be cut. Wrap the paper at least 0.5 cm thick and then tie the paper with string or rubber bands. With the file or glass cutter, scratch a line completely around the bottle at the top edge of the paper. Put the bottle into cold water until the paper is soaked (about five minutes). Remove the bottle from the water, and rotate it in a horizontal position, with the scratch on the glass just above a small, fine flame. Continue this for four or five minutes. If the bottle has not dropped apart, put the bottle vertically into the water. The bottle should break into two parts along the scratch. If it does not, repeat the heating and cooling until it does. It is crucial that the flame be very small so as to heat a minimum of glass on either side of the scratch.

c. Notes

(i) To drill a hole in a glass bottle or jar, follow the procedure outlined for drilling in a glass sheet (I/E2).

G. STOPPERS

Stoppers for use in scientific apparatus are commonly manufactured of either cork or hard rubber.

Rubber Stoppers

Rubber stoppers are more durable for general use than cork stoppers. They are available in standardized sizes, and are manufactured with no holes as well as with one, two or three holes. Although they tend to react with organic solvents like gasoline, they provide an excellent seal in most cases and can even be sterilized. (BIO/VII/A2). If a stopper with holes is specified in the directions for a piece of apparatus, use rubber stoppers with pre-drilled holes if at all possible. If it becomes necessary to drill a hole or holes in a rubber stopper, consult the notes following the discussions of boring and drilling holes in cork stoppers (I/G1 and G2).

Cork Stoppers

Cork stoppers, while generally less expensive than those made of rubber, are not as suitable for general use. They tend to lose their shape after long use, are not available with holes pre-drilled, tend to absorb reagents, and cannot be adequately sterilized. Should it be necessary to bore a hole or holes in a cork stopper for the insertion of glass tubing, one of the following methods may be employed.

G1. Cork Boring

a. Materials Required

Cork stopper

Set of hand cork borers

b. Procedure

If a set of hand cork borers in graduated sizes is available from a scientific supply house, choose a cork borer of the same or slightly smaller diameter as the glass tubing that is to go through the cork.

The cork borer set generally is supplied with a rod to clean pieces of cork out of the borer. Soften the cork by wrapping it in a piece of paper and rolling it gently on the floor under your foot.

With one hand, hold the cork firmly on the table or bench, wide end up. With the other hand, place the cutting edge of the cork borer in the center of the cork. Then with a gentle twisting motion on the cork borer, bore into the cork until the tool is about halfway through the cork.

It is not necessary to push hard; but twist gently with light pressure. Remove the cork borer from the cork and push out small pieces of cork inside it with the cleaning rod.

Turn the cork over and repeat this process until there is a hole through the cork.

c. Notes

(i) If two holes are desired, the first must be bored near one edge of the cork in the manner described above. The second hole is then bored in the same way. A guide line, drawn around the middle of the cork, is helpful in determining the positions of the two holes.

(ii) This method is suitable for boring holes in rubber stoppers. However, the stopper as well as the end of the boring tool should be lubricated with glycerine.

G2. Cork Drilling

a. Materials Required

Cork stopper

Round file

Cloth, or wooden handle

Burner

Brick or asbestos pad

b. Procedure

Soften the cork as described in I/G1 above. Hold the cork, wrapped in cloth or clamped in pliers, securely against the brick or asbestos pad with one hand. Hold the file, wrapped in cloth or in a wooden handle, by its four-sided end in the other hand. Heat the round end of the file in the burner flame. Remove the file from the flame when it glows red hot, and push it gently into the center of the cork. Push it only about half-way through the cork, then remove it.

Turn the cork over, reheat the file, and make another hole to meet the first one.

Allow the file to cool, then enlarge the hole to the desired size by gentle filing.

c. Notes

(i) Care must be taken not to overheat the file, or it may set the cork on fire. Should this happen, blow the flame out quickly.

(ii) Two holes can also be made through the cork with this method.

(iii) Very small holes can be made in corks in the same manner by using heated wire.

(iv) If a hand drill or electric drill is available, holes can easily be bored by using either a regular drill bit or the round file as the drill bit. The cork must be rigidly held in a vise. For an accurate hole, just as with the other methods of drilling, a hole should be drilled halfway through the cork from each side, to meet in the center of the cork.

(v) It is possible to drill holes in rubber stoppers with a hand drill or electric drill, but the hot file method will not work in rubber stoppers.

G3. Inserting Glass Tubing Through a Stopper

a. Materials Required

Glass tubing
Burner
One-hole cork or rubber stopper
Cloth
Glycerine

b. Procedure

Fire polish the end of the tube that is to go into the stopper. Allow it to cool. Hold the tubing about 2 - 3 cm from the fire-polished end in one hand. Lubricate this end of the tube with glycerine. Hold the stopper in the other hand. Gently and carefully push the tube into the stopper with a twisting motion. Do not use too much force or the tube will snap.

When pushing a piece of bent tubing into a stopper, always hold the tube between the bend and the stopper. Do not push on the bend; it is weak and will break easily.

c. Notes

(i) This is a technique that, if improperly done, can be quite dangerous. When done correctly, however, it is quite safe.

II. BURNERS

These have been grouped according to the type of fuel used.

A. SOLID FUEL BURNERS

These are the simplest burners to make, and include candles as well as charcoal burners.

B. LIQUID FUEL BURNERS

These include several types of alcohol burners.

C. GAS BURNERS AND SYSTEMS

These are functional items, providing the cleanest, most intense heat. However, they are somewhat more sophisticated for production purposes.

A. SOLID FUEL BURNERS

A1. Candle Burner

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Shallow Tin Can (A)	5 cm diameter or larger
(2) Heat Source	3	Household Candles (B)	Varies

b. Construction

(1) Container	Select a tin can (A) with low sides.
(2) Heat Source	Melt the wax at the base of the candles (B) and place tnem at equal intervals within the container.

c. Notes

(i) The intensity of the heat produced may be increased by increasing the number of candles, but the total intensity is low.

(ii) The efficiency of a candle burner may be improved by collecting all the wax that melts into the container and using it again with new wicks made from soft string.

(iii) The candle flames tend to deposit soot on the surface of whatever is being heated.

A2. Charcoal Burner *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Empty Metal Can (A)	10 cm diameter or larger

b. Construction

(1) Can

Remove top from can (A). Approximately 4 cm from the bottom of the can, mark off triangular windows all around.

With shears, cut along the sloping sides of each triangle to make the windows. Do not cut along the base line (horizontal edge) of the triangle.

Bend the triangles up to form a tray.

*Adapted from UNESCO, Source Book for Science Teaching, (Paris: UNESCO, 1967), pp 34-35.

c. Notes

(i) The holes permit air to circulate freely to the burning charcoal.

(ii) Comments from users of the charcoal burners indicate that they are hard to start. Also, once started, they present a considerable fire and carbon monoxide risk.

B. LIQUID FUEL BURNERS

B1. Simple Alcohol Burner

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Fuel Container	1	Glass or Metal Container (A)	150-200 ml, approximate capacity
(2) Lid	1	Screw Top (B)	To fit fuel container
(3) Wick	1	Soft Cotton Fiber Cord (C)	Long enough to extend to bottom of container and to cover it.

b. Construction

(1) Fuel Container

Make the fuel container from a glass or metal container (A) with a screw-on metal lid (B). Select a container with a wide base to insure stability.

(2) Lid

Punch a hole in the lid (B) with a nail, making it as round and smooth as possible, with a diameter smaller than that of the wick to be used.

(3) Wick

Select a piece of cord (C) with soft cotton fibers. The wick should protrude 0.5 cm above the surface of the lid.

c. Notes

(i) If a hotter, broader flame is required, punch two holes in the lid and use two wicks to produce a single, broad flame.

(ii) The wick should be soaked in alcohol before lighting the burner.

(iii) Methyl alcohol or denatured ethyl alcohol is the usual fuel used in the burner. Kerosene may also be used, but it tends to produce a smoky flame which blackens heated objects.

(iv) Important: Use a stable container. Otherwise, there is danger that the burner will tip over easily.

(v) If the burner is used for prolonged periods, overheating of the container, with build-up of internal pressure, is possible.

(vi) Make certain that the wick fits tightly into the hole in the lid. Otherwise, it is possible for the flame to climb down the wick into the container.

(vii) A user of alcohol burners notes that those made from 35 mm film cans have several advantages over larger ones made from glass containers. First, they are unbreakable. Second, if the inside is filled with cotton wadding (cotton wool) they are unspillable if knocked over. Also, these small film cans hold only enough for immediate use, so that evaporation losses are not serious.

B2. Modified Alcohol Burner

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wooden Platform (A)	Approximately 10 cm diameter (round), or approximately 10 cm x 10 cm (square)
	1	Metal Lid (B)	To fit fuel container bottom
(2) Fuel Container	1	Glass or Metal Container (C)	100-200 ml capacity
	1	Metal Lid (D)	To fit fuel container top (C)
(3) Wick Holder	1	Metal Tube (E)	Approximately 4 cm long, 0.7 cm or 0.8 cm diameter
(4) Heat Barrier	1	Metal Disc (F)	5 cm diameter or larger
(5) Wick	1	Cord (G)	Approximately 10 cm long, 0.5 cm or more in diameter
(6) Cap	1	Ball Point Pen Top or Metal Tube (H)	To fit wick holder

b. Construction

(1) Base

Nail the metal lid (B) (with a diameter equal to that of the fuel container) to the round or square wooden base (B).

(2) Fuel Container

Select a glass or metal container (C) with a screw-on lid (D).

(3) Wick Holder

Make the wick holder from a metal tube (E) about 4 cm long x 0.7 or 0.8 cm internal diameter, or roll a piece of sheet metal (4 cm x 2.5 cm) into a tube.

Drill a hole in the fuel container lid (D) large enough to allow insertion of the wick holder. Insert the wick holder so that it penetrates about 1 cm into the container. Solder the seam along the tube and between the tube and the lid.

(4) Heat Barrier

Cut the metal disc (F) from metal sheeting, or use a tin can top. The disc should be slightly larger than the fuel container lid (D).

Drill a hole in the center of the disc large enough to allow insertion of the wick holder (E). Insert the wick holder so

that about 1.0 - 1.5 cm protrudes above the disc. Solder the seam between the heat barrier and wick holder.

(5) Wick

Make the wick from a piece of cord (G) or rope with soft cotton fibers. Insert the wick into the wick holder. Trim the wick with scissors so that about 0.4 - 0.5 cm protrudes above the top of the wick holder.

(6) Cap

Use a ball point pen top (H) as a cap or make a metal cap large enough to fit snugly over the wick holder when the burner is not in use. The cap prevents evaporation of the alcohol.

c. Notes

(i) The design of this burner overcomes the major hazards of the simple alcohol burner (II/B1).

(ii) This design can be modified to produce a wide flame that is particularly useful for working with glass. All parts of the design are the same, except for the shape of the wick, wick holder, and cap.

For the wick holder, cut a piece of metal sheeting about 5 cm x 4 cm. Bend it into a flat tube about 2 cm wide and 0.5 cm deep. Solder the seam. Install this wick holder in the fuel container lid and heat barrier just as in the previous design. For the wick, use flat cotton webbing about 2 cm wide and 10 cm long, or braid (plait) a flat wick from six to ten strands of cotton cord or string. Make a cap from metal sheeting to fit snugly over the wick holder when the burner is not in use.

C. GAS BURNERS AND SYSTEMS

C1. Fuel System for Gas Burner *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pressure Unit	1	Metal Drum (A)	Approximately 26 liter capacity
	1	Metal Drum (B)	Approximately 16 liter capacity
	3	Wood (C)	3 cm x 2 cm x 65 cm
	3	Bolts (D)	0.5 cm diameter, 4 cm long
	1	1-Hole Stopper (E)	Approximately 2.5 cm diameter (large end)
	1	Glass Tubing (F)	0.5-0.7 cm diameter, 10 cm long
	1	Container and Sand (G)	Approximately 6 kg
(2) Clamp	1	Screw Clamp (H)	IV/A5
(3) Fuel Unit	1	Metal Can (I)	4 liter capacity, approximately
	1	2-Hole Rubber Stopper (J)	To fit opening in can

*Adapted from C. S. Rao (Editor), Science Teachers' Handbook,(Hyderabad, India: American Peace Corps, 1968), pp 140-141.

	1	Glass Tubing (K)	0.5 cm diameter, 10 cm longer than height of can
	1	Glass Tubing (L)	0.5 cm diameter, 10 cm long
(4) Safety Tank	1	Narrow-neck Bottle (M)	500 ml capacity, approximately
	1	2-Hole Rubber Stopper (N)	To fit bottle
	1	Glass Tubing (O)	0.5 cm diameter, 10 cm longer than height of bottle
	1	Glass Tubing (P)	0.5 cm diameter, 10 cm long
(5) Burner	1	Gas Burner (Q)	II/C2
(6) Connecting Tube	3	Plastic or Rubber Tubing (R)	Approximately 1 cm diameter, and approximately 1 meter long

b. Construction

(1) Pressure Unit

Select two metal drums (A,B) of approximately the same depths, but different diameters, so that one drum (B) will fit inside the other (A). Each drum should have one end open. Bolt the three pieces of wood (C) to the larger drum (A) with the bolts (D) so that the space between them is just sufficient to allow the smaller drum (B) to slide down easily between them.

Use an alcohol lamp to make a 90° bend in the middle of the glass tubing (F), or cut a shorter piece of straight tubing. Fit the glass tube into the stopper (E). Bore a hole near one side in the bottom of the smaller drum (B). Insert the stopper into this hole.

Fill the larger drum (A) with water equal to the volume of the smaller drum.

Fit the smaller drum, open side down, between the wooden uprights of the larger drum.

Push down on the upper (air) drum (B). It should slide down into the lower drum (A). Air should be felt escaping from the glass tubing (F).

Place a can or bucket filled with sand (G) on the air drum, as a weight.

(2) Clamp

Use the screw-type clamp (H) or any standard screw-type clamp to control the air pressure from the fuel tank.

(3) Fuel Unit

Fuel Unit
(Cross-section)

Make the fuel container from a metal drum (I) or can with a single outlet, rather than a lid. Fit the drum with a two-hole rubber stopper (J).

Make a 90° bend about 5 cm from one end of the longer piece of glass tubing (K), or use a slightly shorter piece of straight tubing.

Make a 90° bend in the middle of the short piece of glass tubing (L).

Insert both pieces of tubing into the stopper as illustrated.

Fill the can about 3/4 full of gasoline (petrol).

(4) Safety Tank

Select a glass or metal container (M) with a narrow neck. Fit the container with the two-hole rubber stopper (N).

Bend both pieces of glass tubing (O,P) as described above, and insert each into the stopper as illustrated.

Fill this container about 1/3 full of water.

(5) Burner

Construct a Bunsen burner (Q) as described in the next section (II/C2).

(6) Connecting Tubing

Use flexible tubing (R) (rubber or plastic) to connect the

apparatus as illustrated.

Connect the tubing from the Pressure Unit (1) with the long glass tube of the Fuel Unit (3).

Connect the tubing from the short glass tube of the Fuel Unit (3) with the long glass tube of the Safety Tank (4).

Attach the connecting tubing from the short glass tube of the Safety Tank (4) to the Bunsen burner (5). Take care to see that the tubing is not kinked anywhere.

When all components are assembled and correctly connected, remove the weight and stopper from the upper (air) drum. Lift the drum until its lower edge is just below the water level in the lower drum. Replace the stopper and check to see that it is tight, and replace the weight on top of the drum.

c. Notes

(i) As the air drum sinks into the water of the lower drum under its own weight and the pressure of the weight on top, the air thus displaced is driven into the fuel drum and bubbles up through the petrol. The petrol evaporates as the air passes through it, and the air-gas mixture is driven through the water in the safety tank to the burner.

(ii) This system is potentially dangerous because the petrol-air mixture present from the fuel tank is an explosive mixture, but several safety precautions have been incorporated into the design.

The greatest safety factor is the needle valve in the burner; even when the burner occasionally "backfires" (the flame jumps down from the end of the burner tube to the needle opening) the flame is very unlikely to move back through the needle's narrow opening. In the unlikely event that a flame should move back down

the tubing, the safety tank prevents it from reaching the fuel drum. As a further safety measure in the safety tank, the stopper should be snug, but not jammed tightly into the neck of the container. Thus, should the flame move back into the safety tank, it will be more likely to blow the stopper out of the tank than to blow the tank apart.

Despite the built-in safety precautions, however, feedback comments suggest extreme care in the use of this system.

(iii) In the system described here, a glass bottle, encased in a cage of wire mesh for additional safety, was used as a water tank. This made it possible to observe the rate of bubbles in the water, an indicator of the pressure in the system. A fairly rapid rate of bubbles, about 100 or more per minute, was necessary to produce a burner flame 3 - 4 cm high. It is recommended, however, that once the bubbling rate is established, a metal safety tank of similar size be substituted for the glass bottle.

(iv) A weight of approximately 5.5 kg on an air drum with an area of 490 cm^2 (diameter 25 cm) provided 11 g/cm^2 pressure to run the Bunsen burner described in the following section (II/C2) for about a half-hour.

(v) The system and dimensions described here constitute a small, laboratory version suitable for running one Bunsen burner. For a larger system, the same components and principles apply, but experimentation on the details of construction will be necessary. For example, a larger pressure system, with a large, heavy oil drum for the upper drum would provide pressure for a longer period of time and might not require a weight on top. An air pump could be added to fill the drum with air without lifting it.

C2. Gas Burner *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Burner Tube	1	Copper Tubing (A)	10.5 cm long, 1 cm dia[illegible]
(2) Air Control Sleeve	1	Metal Sheet (B)	3 cm x 3.[illegible] cm
(3) Gas Valve	1	Hypodermic Needle (C)	18 gauge (0.125 cm outside diameter)
	1	Adhesive Tape or Electrical Tape (D)	Approximately 1 cm wide, 15-30 cm long
(4) Base	1	Wooden Block (E)	10 cm x 10 cm x 2 cm
	2	Wooden Block (F)	10 cm x 5 cm x 2 cm
(5) Gas Tubing	1	Rubber or Plastic Tubing (G)	Approximately 15-20 cm long, approximately 0.6 cm internal diameter
	1	Metal Tube (H)	3 cm long, 1 cm diameter

*Adapted from C. S. Rao (Editor), Science Teachers' Handbook, (Hyderabad, India: American Peace Corps, 1968), pp 138, 141.

b. Construction

(1) Burner Tube

Drill two holes on opposite sides of the copper tube (A) about 2 - 2.5 cm from one end. Enlarge the holes to an oval shape, about 1 cm long x 0.6 cm wide.

(2) Air Control Sleeve

Lay the metal sheet (B) flat on a table. Lay the burner tube on it with the end of the tube with the holes in it about 1.0 cm from the 3.5 cm edge. Actually, the holes themselves should be 1.0 cm from the 3.5 cm edge.

Use a pencil to trace the outline of one of the holes in the tube onto the metal sheet. Cut this hole out. Wrap the metal sheet around the burner tube until it forms a cylinder. Align the hole in the metal sheet with one of those in the tube. Trace the outline of the other hole in the tube onto the metal sheet. Remove the metal sheet, and cut out the second hole.

Reroll the air control sleeve and place it in position on the burner tube.

(3) Gas Valve

Cut the top off the hypodermic needle (C) so that about 1 cm of the needle remains. File the cut end of the needle open.

Side View

Wrap the adhesive tape (D) or electrical tape around the needle holder until the base of the needle will fit tightly into the bottom of the burner tube. The open end of the needle should be near the middle of the air holes.

(4) Base

Drill a hole approximately 1.2 cm in diameter in the center of the square piece of wood (E). Enlarge the hole with a file to tightly hold the burner tube and gas tubing in place.

Nail the two rectangular pieces of wood (F) to the square to form the sides of the base.

(5) Gas Tubing

Connect one end of the plastic or rubber tubing (G) to the bottom of the burner tube. Then push the burner tube through the hole in the top of the base. It should fit snugly in place and should not wobble.

Pass the other end of the gas tubing through one open side of the base. Insert the small metal tube (H) into the open end of the gas tubing.

Connect tubing from the gas supply to this metal tube.

c. Notes

(i) This burner has been tested with both commercially supplied natural gas and with the gas generating system described in the previous section II/C1.

(ii) When the burner is lit, the air control sleeve can be used to control the nature and intensity of the flame. The sleeve is closed when its holes and the holes in the burner tube are not lined up with each other. No air enters the burner tube. The flame is smoky, yellow, and glowing. It gives little heat. The absence of air prevents the gas from being completely burned.

When the sleeve is turned so that its holes and those of the burner tube are partly lined up, some air enters the burner tube. The flame is almost colorless, and does not glow. It is quite hot. The gas is more completely burned in this flame because of the presence of some air.

When the holes of the air control sleeve completely match those in the burner tube, the maximum amount of air enters the burner tube.

This produces a very hot, roaring flame with a bright blue center cone. The gas is completely burned, producing the hottest flame, because there is plenty of air entering the burner tube.

Purplish Cone - hot part of the flame, called the oxidizing flame. Combustion of the gas is most complete.

Hottest part of the flame - just above the inner blue cone of flame.

Blue cone - not as hot as the outer cone because there is insufficient oxygen mixed with the gas to completely burn it. Called the reducing flame because it can take oxygen away from some oxides.

Dark cone - not a flame at all. It is filled with a mixture of unburned gas and air coming from the barrel.

Use a blue flame, about 4 cm high, for glass-working operations and most other heating operations. Adjust the gas supply and air control sleeve of the burner to produce a quiet blue flame with distinct cones.

(iii) In use this burner produced an excellent flame suitable for working soft glass and for blowing small bulbs in 0.3 cm and 0.5 cm soft glass tubing. However, the burner tube tended to heat up after a few minutes use. The larger diameter burner, of slightly more complex design, avoids this difficulty to some extent.

(iv) If a larger diameter tube (e.g., 1.5 cm diameter) is used for the burner tube, several alterations must be made to the design of the burner. First, a larger diameter syringe needle is needed (16 gauge, 0.15 cm outside diameter), and

it must be cut off shorter, i.e., 0.5 cm rather than 1.0. Secondly, the end of the burner tube must be flattened slightly to restrict the flow of air/gas mixture through it. Thirdly, the connection between burner tube, gas valve, and gas tube must be altered. One way in which this can be done is to drill a hole 1.0 cm in diameter through a cork. Enlarge the hole at one end to 1.5 cm diameter, and 1.5 cm deep. Insert a 1.0 cm diameter piece of metal tubing through the hole and place a short (1.0 cm) piece of rubber tubing on the end of it. Insert the needle into the rubber tube (the base may have to be built up with tape). Insert the burner tube into the enlarged hole in the cork. Make certain the fit is tight. Finally, insert the cork into the hole in the base, put the air control sleeve in place, and attach the gas tubing.

Cross Section

If, when this burner is in use, the flame should tend to blow itself out because the tube opening is too wide, decrease it further by pinching with pliers.

(v) It must be noted that various components of the burner design are dependent on the diameter of the burner tube. These include burner tube length, size of the air holes, gauge and length of the needle, width at the top of the tube, and various connecting devices such as metal and rubber or plastic tubing. For example, if the diameter of the burner tube is increased, the diameter of the needle used and the length of the tube must also be increased, but the size of the opening at the top of the tube must be decreased. Therefore, if tubing of a size different from those described here is used, experimentation with the other components will be necessary in order to construct a working Bunsen burner.

C3. Wing Tip

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Wing Tip	1	Metal Sheet (A)	6 cm x 4 cm
	1	Metal Sheet (B)	6 cm x 4 cm

b. Procedure

(1) Wing Tip

0.8
4
2.5
Metal Sheet (A)
1.0
1.0
0.5
0.5 of Circumference of Burner Tube

Measure the circumference of the burner tube. Draw and cut out a paper pattern as illustrated. Cut one piece of this pattern from the metal sheeting (A). Cut on the solid lines. Bend on the dotted lines.

Cut another piece from the metal sheeting (B), but trim the flaps on the wing to 0.4 cm. Cut on the solid lines. Bend on the dotted lines.

Bend the wing flaps on piece (B) at 90°. Bend the wing flaps of piece (A) around the outside of the flaps on (B). Pinch the flaps on (A) to hold (B) in place.

Place the wing tip on the burner tube, such that the wing extends above the burner tube.

Bend the support strip flaps of (B) and (A) to fit snugly around the burner tube. Small holes left at the corners of the flaps will not affect the wing tip's performance.

c. Notes

(i) The wing tip is an accessory used with the gas burner when a wide flame is desired. It is especially useful for working with glass.

III. MEASURING APPARATUS

A. DEMONSTRATION DEVICES

These devices demonstrate thermal expansion of liquids and solids.

B. VOLUMETRIC MEASURES

These are all measures of liquid volume and range from single volume measures like volumetric flasks to multiple measures such as measuring cylinder. Also included under this heading is the specific gravity bottle.

A. DEMONSTRATION DEVICES

A1. Demonstration Thermometer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Thermometer	1	Pill Bottle (A)	7 cm high, 3 cm diameter
	1	Pill Bottle Cap (B)	To fit pill bottle (A)
	1	Glass Tubing (C)	25 cm long, 0.5 cm outside diameter, 0.3 cm inside diameter

b. Construction

(1) Thermometer

Make a hole in the pill bottle cap (B) (or a suitably sized cork) through which the glass tubing (C) is inserted.

Be certain the seal is airtight (it may be necessary to use glue to insure an airtight seal).

Fill the bottle (A) completely with water or other liquid. Force the cap or cork down onto the mouth of the bottle so that some liquid is forced up into the tube and the rest of the excess liquid spills over the side of the bottle where it is wiped away. Some liquid must rise up far enough into the tube so that it can be seen.

c. Notes

(i) This thermometer is used simply to demonstrate the expansion of a liquid as it is used in standard thermometers. Putting the demonstration thermometer into a 60°C water bath will cause the level of the water in the tube to rise about 2 cm.

(ii) Be certain to eliminate all air bubbles from the bottle unless it is desirable to show the effect of having air trapped in the bottle.

A2. Bi-Metal Strip

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bi-metal Strip	1	Steel Strapping (A)	20 cm x 1.2 cm x 0.8 cm
	1	Aluminum Sheet (B)	20 cm x 1.2 cm x 0.6 cm
	9	Nails (C)	#4 d (0.2 cm diameter with large heads)
(2) Handle	1	Wood (D)	1.5 cm x 2.0 cm x 10 cm

b. Construction

(1) Bi-metal Strip

Side View

Hold the two pieces of metal (A,B) tightly together, and drill nine holes through both at 2 cm intervals beginning 1.0 cm from one end. These holes must be very slightly larger in diameter than the nails (C) used.

Cut the head off each nail (C) with a hacksaw, chisel, or tin snips so that the portion with the head is about 0.5 cm long. Push the nails through the holes in the two strips (A,B) and hammer down the cut ends to rivet the two strips together. It is best to begin by riveting the strip at its center and moving out toward each end at the same time. The strips should be firmly held together all

(2) Handle

along their length.

Make a narrow notch in one end of the wood (D) the width of a saw blade. This notch ought to be about 1.5 cm deep. Insert the end of the bi-metal strip into this notch to complete the device.

c. Notes

(i) This device is used to demonstrate the fact that metals expand when they are heated. When the bi-metal strip is held in a flame, it will bend in the direction of the steel since the aluminum expands more than does the steel.

(ii) Different combinations of metals (e.g., copper and steel, brass and aluminum, etc.) can be used with the same results.

(iii) The metal strips may be soldered together as opposed to riveted. Melt a thin layer of solder onto the surface of one of the two strips. Lay the other strip on top of it and hold the soldering iron down on both strips until the solder melts between the two strips. Keep the two strips pressed together with a screwdriver or other object to prevent them from coming apart before the solder cools. Repeat this process until the two strips are soldered all along their lengths. (Note: This procedure will not work if aluminum is used as one of the metals unless special solder is used.)

B. VOLUMETRIC MEASURES

B1. Burette

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Tube	1	Glass Tube (A)	45 cm long, 1.3 cm outside diameter, 1.1 cm inside diameter
	1	Glass Tube (B)	4 cm long, 0.7 cm outside diameter, 0.5 cm inside diameter
	1	Glass Tube (C)	9 cm long, 0.7 cm outside diameter, 0.5 cm inside diameter
	1	Rubber Tubing (D)	10 cm long, 1.0 cm outside diameter
(2) Clamp	1	Pinch Clamp (E)	IV/A4

b. Construction

(1) Tube

Insert the glass tubing (B) into the end of the rubber tubing (D) so that the ends of both pieces of tubing are even. Insert this end into one end of the large glass tubing (A) for a distance of about 1 - 1.5 cm. If the seal between the rubber and large glass tubing is not watertight, use thin rubber sheeting (e.g., balloon material) to fill in the gas. Seal this joint with glue to insure a watertight fit. Draw out one end of the remaining piece of glass tubing (C) in a flame to form a narrow neck. Break off the neck, and fire polish the end of the tube. Insert the wide end of this tube into the end of the rubber tubing (D) for a distance of about 2 cm. Check the tube now for watertightness.

(2) Clamp

Use the clamp (E) to regulate flow in the burette. Be sure the clamp is large and strong enough to completely shut off flow from the burette.

c. Notes

(i) The most common use of the burette in chemistry is in doing titrations.

Quite often they are used in pairs, and must always be supported by a stand.

(ii) Each burette needs to be fitted with a scale. Attach a long, thin strip of paper to the burette tube with transparent tape. Fill the burette from a known source (e.g., a plastic syringe) one milliliter at a time and mark the level of the meniscus on the paper. Place the "0" mark in such a way that several milliliters of liquid will still remain in the burette when "0" is reached as this will insure greater accuracy.

(iii) A glass bead just slightly larger than the internal diameter of the rubber tubing may be used in place of the pinch clamp. Push the bead into the rubber tubing before inserting the glass nozzle. The bead will seal the rubber tube. To dispense liquid from the burette, squeeze the tube between thumb and forefinger at the location of the head.

Cross Section

(iv) Because of the use of rubber tubing in this burette, it is not suitable for use with strong corrosives that attack rubber.

B2. Measuring Glass

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bottle	1	Glass Bottle (A)	Variable

b. Construction

(1) Bottle

Use a glass bottle (A) with straight sides and a flat bottom. Make graduations by calibrating the bottle using a known source. The graduations may be tape, paint, or scratches on the glass itself.

c. Notes

(i) Inaccuracies may occur due to transfer of liquid from the known source, failure to wait for liquid to "settle" before making calibration marks, and human error in marking exact height of liquid. However, for most purposes these measuring glasses are adequate.

(ii) Graduations may be made every 10, 25, 50, or 100 ml, depending on the size of the bottle and the uses to which it is to be put.

c. Notes

(iii) If the bottle is narrow enough in diameter, the graduations may be made closer together (i.e., every milliliter), but the accuracy will not approach that of a commercially made graduated cylinder.

B3. Dropper

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Dropper	1	Dropper	BIOL/II/A6

b. Construction

(1) Dropper — Construct the dropper as described in BIOL/II/A6.

c. Notes

(i) Since commercial droppers are usually readily available and inexpensive, this item is as easily purchased as it is improvised.

B4. Pipette

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pipette	1	Transfer Pipette	BIOL/VII/A5

b. Construction

(1) Pipette — Construct the pipette as described in BIOL/VII/A5.

c. Notes

(i) The pipette is used to transfer and precisely measure quantities of liquids.

B5. Volumetric Flasks

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bottle	1	Transparent Glass Bottle (A)	Variable
	1	Bottle Cap (B)	To fit bottle (A)

b. Construction

(1) Bottle — Select any common glass bottle (A) with a narrow neck.

(2) Cap — Use a cap seal (B) which will be airtight to prevent leakage and evaporation.

c. Notes

(i) The flasks must be calibrated from a known source. Put a single calibration mark on the neck of the bottle to indicate its capacity. This may be done with paint, tape, a scratch mark, etc.

B6. Specific Gravity Bottle

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bottle	1	Pill Bottle (A)	5 cm high, 3 cm diameter
	1	Rubber or Cork Stopper (B)	To fit bottle (A)
	1	Glass Tube (C)	8 cm long, 0.5 cm outside diameter, 0.3 cm inside diameter

b. Construction

(1) Bottle

Simply insure that there are airtight seals between the stopper (B) and bottle (A), and between the glass tube (C) and cork (B).

c. Notes

(i) To use the specific gravity bottle, first remove the stopper and tubing and fill the bottle to the brim with the liquid to be measured. Reinsert the stopper, making sure liquid flows completely out of the end of the tubing and that there is no air trapped in the bottle. Wipe away the excess liquid on the outside of the bottle. Accurately weigh this amount of liquid and subtract the mass of the empty specific gravity bottle. Compare the mass of the liquid to that of an equal

volume of water (found in the same way) to find the specific gravity of the liquid.

(ii) A screw-top bottle may be used instead of the stopper arrangement. Punch a hole in the top and seal the joint between the tubing and top with waterproof cement.

IV. SUPPORTS, STANDS, AND HOLDERS

A. HOLDERS

Holders are classified as small, portable, hand-held devices used to support other pieces of apparatus.

B. SUPPORTS AND STANDS

These devices are used to hold items stationery for relatively long periods of time.

A. HOLDERS

A1. Tweezers (Forceps)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Tweezers	1	Forceps	BIOL/II/A4

b. Construction

(1) Tweezers — See BIOL/II/A4 for construction details.

c. Notes

(i) Uses of forceps in chemistry operations include the handling of small items or radioactive materials.

Fasten one strapping clamp to the short end of each of the handles with the nails (C).

Clamp a pencil or stick of about 0.8 cm diameter in a vise. Starting at the center of the wire (D), coil the wire around the pencil. Make at least six turns, or a coil that extends beyond the width of the wood block (2 cm) by one wire-thickness on each side. Leave at least 9 cm of straight wire at each end of the spring.

Approximately 4 cm from the spring, make a 90° bend in each straight section of wire, as shown. One cm from each of the first bends, make a second 90° bend.

Slide the spring on to one of the handles as shown.

Slide the second handle into place.

Trim excess wire to within 1.5 cm of the edge of the handle. Bend this remaining wire around handles to hold the spring in place.

Top View

Lay the holder on its side. Slide one small piece of strapping under the spring as shown. Secure the strapping in place on one handle with one nail. Nail a second guiding nail into the other handle just at the edge of the strapping. Turn the holder over and repeat with another small piece of strapping. These guides keep the handles from twisting out of alignment.

c. <u>Notes</u>

(i) This design is based on the spring-type clothespin. If one is available, it will be a helpful construction guide.

(ii) Squeezing the handles together will cause the clamp to open and close.

(iii) The sizes of the components used in this item will vary with the use to be made of the holder. The clamp and handle can be reduced in size for use with test tubes, or enlarged for use with large flasks.

(iv) For a simpler version of this design, three or four strong rubber bands provide the spring action. Cut the handles and attach the clamps as described. Then place the two handles together as indicated in the diagram. Wrap the rubber bands around the top part of the handles to draw them together. The chief problem with using rubber bands is that they will deteriorate and must be replaced from time to time.

Rubber Bands

A3. Test Tube Holder

a. Material Required

Components	Qu	Items Required	Dimensions
(1) Clamp	2	Metal Strapping (A)	20 cm long
	1	Thin Wire (B)	Approximately 0.1 cm thick, 4-5 cm long
(2) Handle	1	Wood Block (C)	Approximately 10 cm x 3 cm x 2 cm

b. Construction

(1) Clamp

Bend two loops in each piece of strapping (A) as shown. Fit the smaller loops to the test tubes to be used. Wrap a small piece of wire (B) around the two pieces of strapping at the point where they curve inward, just behind the front loops, to hold the pieces together.

(2) Handle

Cut a slit about halfway down the center of the block (C). Insert the flat portions of the strapping clamps into the slit. Secure the clamp to the handle with two nails.

c. Notes

(i) To open this clamp, squeeze together the large loop between the handle and the wire. Release the loop to close the clamp.

(ii) This design is best suited for small, light-weight test tubes.

(iii) A quick and convenient holder for handling hot test tubes can be made with a piece of paper measuring approximately 15 cm x 8 cm. The paper is folded into

thirds, lengthwise, to form a strip. This strip can be wrapped around a test tube near the top. then grasped tightly, next to the test tube.

A4. Wooden Pinch Clamp

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handles	2	Wooden Strips (A)	2 cm x 8 cm x 0.5 cm
(2) Fulcrum	1	Metal Staple or Tack (B)	1 cm wide
(3) Band	2	Rubber Bands (C)	0.5 cm x 9 cm

b. Construction

(1) Handles

Sand any splinters or rough edges from the wood strips (A).

(2) Fulcrum

Drive the staple (B) or tack into the middle of one of the handles. Allow about 0.5 cm of the staple or tack to protrude from the wood.

(3) Band

Place the handles together with the fulcrum between them. Wrap the two rubber bands (C) tightly around the handles at a point just in front of the fulcrum.

c. Notes

(i) If the rubber bands are sufficiently tight, it should be possible to

completely close off the flow of a liquid such as water through 1 cm wide rubber tubing,

(ii) To completely close off plastic tubing and heavier rubber tubing, it will be necessary to bend the tubing back upon itself and secure the clamp at the bend.

(iii) If pinch-type clothespins are available, they may be substituted for this clamp. However, it will be necessary to bend rubber tubing as well as plastic tubing back upon itself, as in the above illustration, in order to completely close the tubing with a clothespin clamp.

A5. Wooden Screw Clamp

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jaws	2	Wood (A)	3.5 cm x 3.5 cm x 0.7 cm
(2) Bolt Assembly	1	Bolt (B)	0.5 cm diameter, approximately 4-5 cm long
	1	Wing Nut (C)	To fit bolt (B)

b. Construction

(1) Jaws

Sand the wood squares (A) to remove rough edges and splinters. Drill a hole 0.6 cm in diameter in the center of each square.

(2) Bolt Assembly

Insert the bolt (B) through the hole in each square and check to see that the holes are just large enough to permit the bolt to slide through easily. Screw the wing nut (C) in place on the bolt.

c. Notes

(i) To use this clamp with rubber tubing, a short (approximately 4 cm long) section of tubing of the same type as that in use is cut. The tubing in use is

passed through the jaws on one side, as close to the bolt as possible. The short section of tubing is passed through the jaws on the opposite side to balance the force of the clamp. By turning the wing nut to tighten the clamp, the flow of a liquid or gas through rubber tubing can be controlled or shut off completely.

(ii) The flow rate of a liquid or gas through plastic tubing can be controlled in the same way, but the stiffness of plastic tubing makes it difficult to close the tubing completely. To close plastic tubing, it is necessary to bend the tubing back on itself, passing each section of the tubing through the clamp and tightening the wing nut as much as possible.

B. SUPPORTS AND STANDS

B1. Wire Gauze

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Wire Gauze	1	Wire Mesh (A)	Approximately 10 cm x 10 cm of heavy guage wire

b. Construction

(1) Wire Gauze

Cut the wire mesh (A) to a size approximately 10 cm x 10 cm. Trim off sharp ends.

c. Notes

(i) This item is generally used in conjunction with the tripods and ring stand described in the sections that follow. The wire screen is placed on the tripod, heating stand, or ring to support a flask or beaker. A burner may be placed beneath the stand to heat the contents of the container.

B2. Heating Shelf

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Shelf	1	Tin Can Top or Bottom (A)	10 cm diameter or larger

b. Construction

(1) Shelf

Remove the top (A) or bottom from a tin can. Punch many holes in it with a large nail.

c. Notes

(i) This item is used in the same way as the wire gauze (IV/B1); that is, to support a flask, beaker, or other container upon a tripod or similar support.

(ii) This is also a useful item to keep hot glass from contacting the tabletop.

B3 (1). Tripod (Tin Can)

a. Material Required

Components	Qu	Items Required	Dimensions
(1) Tin Can Tripod	1	Tin Can (A)	Approximately 8 cm diameter, 12 cm high

b. Construction

(1) Tin Can Tripod

Cut a circle about 5 cm diameter from the bottom of the can (A). Mark the position for three legs, evenly spaced around the can. Allow a ring of about 1.5 cm at the top of the tripod before marking the legs. Allow approximately 2.5 cm for the width of each leg. Then cut along the marked lines to produce the three legs. With pliers, bend in the outside edge of each leg slightly to provide extra support.

c. Notes

(i) This tripod is simple to make, but it must be used with caution because of sharp edges and instability. It is suitable for supporting lightweight items, such as a funnel.

B3 (2). Tripod (Strappings)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Top	1	Metal Strapping (A)	1.5 cm x 42 cm
(2) Legs	3	Metal Strapping (B)	1.5 cm x 34 cm

b. Construction

(1) Top

Bend the section of strapping (A) into a circle and secure the ends with a metal rivet.

(2) Legs

Fold each of the three sections of strapping (B) in half and pinch the fold closed. Secure the open ends of each leg to the top with metal rivets.

c. Notes

(i) The dimensions given produce a tripod that is useful for most applications, but this tripod can also be made larger or smaller by varying the length of the strapping used.

B3 (3). Tripod (Wire)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Wire Tripod	3	Heavy Wire	0.2 cm diameter, 40 cm long

b. Construction

(1) Wire Tripod

Twist together the ends of two pieces of wire (A) for approximately 15 cm to form one leg. Twist the free ends of these two pieces together with each end of the third piece of wire. Make each twisted leg 15 cm long. Bend the legs down to form a tripod with a level top, as illustrated.

c. Notes

(1) This size tripod is useful for most applications, but it may also be made larger or smaller by varying the length of the wire used.

B4. Collapsible Heating Stand

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Legs	2	Thick Wire (A)	0.4 cm diameter, 45 cm long
(2) Frame	2	Metal Sheeting (B)	10 cm x 3 cm
	2	Metal Strapping (C)	1.5 cm x 16 cm

b. Construction

(1) Legs

Bend the two pieces of heavy wire (A) to the shape indicated.

(2) Frame

Strapping

Roll each of the rectangular pieces of metal sheeting (B) into long tubes that just fit around the legs.

Roll 3 cm at each end of the metal strapping pieces (C) around each end of the tubes.

Insert the free ends of the legs (A) into the ends of the tubing (B) to complete this stand.

c. Notes

(i) Like the tripods, this stand is generally used with wire gauze (IV/B1) or heating shelf (IV/B2).

(ii) When this stand is not in use, the legs may be removed for ease in storing.

B5. Ring and Burette Stand with Attachments*

*Adapted from C. S. Rao (Editor), Science Teachers' Handbook, (Hyderabad, India: American Peace Corps, 1968), pp 144-146.

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Ring and Burette Stand	1	Wood Block (A)	14 cm x 18 cm x 2 cm
	4	Wood Block (B)	2 cm x 4 cm x 1.5 cm
	1	Wood Block (C)	3 cm x 2 cm x 40 cm

(2) Burette Clamp	1	Metal Strapping (D)	1.5 cm x 27 cm
	2	Metal Strapping (E)	1.5 cm x 5 cm
	1	Heavy Wire (F)	0.2 cm diameter, 10-12 cm long
(3) Large Clamp	1	Metal Strapping (G)	1.5 cm x 35 cm
	2	Metal Strapping (H)	1.5 cm x 5 cm
	1	Heavy Wire (I)	0.2 cm diameter, 10-12 cm long
(4) Ring	1	Metal Strapping (J)	1.5 cm x 50-60 cm
	2	Metal Strapping (K)	1.5 cm x 5 cm
	1	Heavy Wire (L)	0.2 cm diameter, 10 cm long
(5) Support Block	1	Wood Block (M)	5 cm x 2 cm x 4 cm
	2	Nails (N)	0.35 cm diameter, 8 cm long

b. Construction

(1) Ring and Burette Stand

Sand all the wood blocks to remove splinters and rough edges. Nail a small wood block (B) to each corner of the flat block (A) to make feet.

In the center of one of the short sides of the base (A) cut a rectangular notch 3 cm long x 2 cm wide.

Drill 0.6 - 0.7 cm holes at 1 cm intervals all the way through the long block (C) as shown.

Fit this block into the rectangular notch in the base (A) and nail it in place to form the upright.

(2) Burette Clamp

Bend the piece of metal strapping (D) as shown. Adjust the stand attachment section so that it will fit securely around the upright of the stand, yet be able to slide up or down along the upright.

Tightening Clip (E)

Bend two small pieces of strapping (E) as indicated to form tightening clips. Fit them around the straight section of the burette clamp to hold the clamp tightly closed.

Tightening Clip (E)

Adjustment Pin (F)

Bend a 10 - 12 cm piece of heavy wire (F) as indicated to make an adjustment pin. Adjust the width between the legs to match the holes drilled in the upright.

Drill a hole approximately 0.4 cm diameter in the burette clamp as shown.

To position the burette clamp on the stand, slide the rectangular section of the clamp along the upright to the desired height, with the clamp facing the base of the stand. Align the hole in the burette clamp with a hole in the upright. Insert one of the legs of the adjustment pin through the burette clamp and into the upright. Insert the other leg of the pin into the next higher hole of the upright.

(3) Large Clamp

Bend the piece of strapping (G) in the same general shape as the burette clamp, but slightly larger.

Construct two tightening clips (H) just as with the burette clamp. Position the clips on the clamp to hold it closed.

Construct an adjustment pin from a piece of heavy wire (I). Follow the procedure given for the burette clamp.

Drill a hole in the large clamp for the adjustment pin, as described for the burette clamp.

(4) Ring

Bend the piece of metal strapping (J) into the shape shown. Bend the ends of the strapping into loops approximately 0.4 cm diameter.

Make two tightening clips according to the directions given with the burette clamp from the strapping (K). Secure them in the positions shown.

Construct a pin to hold the end loops together by bending the length of heavy wire (L) in half.

To position the ring on the stand, slide the rectangular section of the ring along with the upright to the desired height, with the clamp facing the base of the stand. Push the pin through the end loops.

(5) Support Block

Drive two nails (N) all the way into a small block of wood (M) 1 cm apart.

Position the support block to prevent the front of the ring from leaning forward under the weight of materials placed on it. Insert the two prongs of the support block into the two holes in the upright just below the ring.

c. Notes

(i) To loosen the burette clamp or large clamp, slide the tightening clips toward each other. To tighten, slide the clips away from each other.

(ii) Although the burette clamp and large clamp have adjustment pins to hold them in place, they are much more stable when the support block is pushed into theupright immediately beneath the clamp. This prevents the burette clamp or large clamp from leaning forward.

(iii) The ring will safely support masses up to about 1 kilogram. It can support round-bottomed containers or flat-bottomed containers with a diameter slightly larger than that of the ring. To support smaller containers, a wire gauze (IV/B1) or heating shelf (IV/B2) may be placed on the ring. For large conatiners, a more stable support, such as one of the tripods (IV/B3) or the collapsible heating stand (IV/B4) is recommended.

B6. Multipurpose Stand

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	9 cm x 4 cm x 18 cm
(2) Flask Support	1	Heavy Wire (coat hanger) (B)	0.2 cm diameter, 35 cm long
	1	Heavy Wire (coat hanger) (C)	0.2 cm diameter, 40 cm long
(3) Test Tube Support	4	Heavy Wire (coat hanger) (D)	0.2 cm diameter, 15-20 cm long
(4) Heating Clamp	1	Heavy Wire (coat hanger) (E)	0.2 cm diameter, 20 cm long

b. Construction

(1) Base

Drill seven holes approximately 0.2 cm in diameter into the wood block (A) as shown. If a larger block is used, or if more attachments are desired, drill more holes.

(2) Flask Support

Bend the piece of heavy wire (C) as shown to form the base of the flask support. Make the circular loop about 6 cm in diameter.

Bend the shorter piece of heavy wire (B) into a loop to form a support for the neck of a flask or light-bulb flask (IV/A1). Make the open loop about 4 cm in diameter.

Insert the two sections of the support into adjacent holes in the base. Adjust them so that they will support a flask or light-bulb flask as illustrated.

(3) Test Tube Support

Use pliers to bend each of the pieces of heavy wire (D) around a wooden rod or test tube of the desired diameter (2 cm for example). Follow the steps illustrated.

Insert the supports into holes in the base.

(4) Heating Clamp

Bend the piece of heavy wire (E) into loop just as for the test tube support shown above. However, tilt the loop at an angle, rather than vertically as was done for the test tube supports. Insert the heating clamp into one of the holes in the base.

c. Notes

(i) Sizes and number of the supports constructed, as well as the size of the base, may be varied to suit individual needs.

(ii) The heating clamp is used to hold a test tube at an angle while its contents are heated. Supporting the test tube at an angle presents a greater area to be heated. As a safety measure, it allows the mouth of the test tube to be pointed away from everyone in the vicinity.

B7. Rack for Light-Bulb Glassware

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	8 cm x 24 cm x 2 cm
	1	Wood (B)	9 cm x 24 cm x 2 cm
	1	Wood (C)	4 cm x 24 cm x 2 cm
(2) Spring Clamp	3	Metal Strapping (D)	1 cm x 14 cm

b. Construction

(1) Base

Drill or cut three circular holes, 6 cm in diameter in the large piece of wood (A). Allow about 1.5 cm between holes.

Attach top (C) and upright (B) with glue and screws as shown.

(2) Spring Clamp

Drill a hole approximately 0.5 cm diameter in the center of each of the pieces of metal strapping (D). Bend each piece of metal strapping into the shape shown.

Center each clamp over each hole in the base. Secure each clamp to the top (horizontally) piece of the base with a screw.

c. Notes

(i) The spring clamp holds the neck of a light-bulb flask securely, while the hole in the base supports the round bottom of the flask.

(ii) This design may be modified to accommodate more flasks, or flasks of different sizes.

B8. Stand for Light-Bulb Glassware

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Flask Stand	1	Wood Block (A)	9 cm x 9 cm x 4 cm

b. Construction

(1) Flask Stand

Drill or cut a circular hole through the center of the block (A). Adjust the diameter of the hole to the size of the light-bulb flask used:

6 cm diameter hole for bulbs from 60 to 200 watts. 7 cm diameter hole for larger bulbs.

c. Notes

(i) Another stand for a single piece of light-bulb, or any round-bottomed glassware, can be made with a piece of heavy rope approximately 3 cm in diameter.

The rope is cut to a length slightly shorter than the maximum circumference of the flask, and the ends of the rope are taped or spliced together to form a ring.

B9. Bamboo Test Tube Rack

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood Block (A)	1 cm x 7 cm x 18 cm
(2) Test Tube Holder	6	Bamboo Sections (B)	Approximately 2.5 cm outside diameter, 10 cm long

b. Construction

(1) Base

Sand the wood block (A) to remove splinters and rough edges.

(2) Test Tube Holder

Select bamboo sections (B) with thick walls (at least 0.2 cm). Cut away approximately half the length of each bamboo section, but leave one upright piece as shown. Cement these cylinders to the base.

c. Notes

(i) The upright section remaining on each bamboo cylinder is used to support test tubes upside down for drying.

(ii) The size of the base may be varied to accommodate a convenient number of bamboo cylinders. The diameter of the bamboo cylinders may be varied to suit the size of the test tubes used.

B10. Wooden Test Tube Rack

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Test Tube Rack	2	Wood (A)	8 cm x 20 cm x 1 cm
	2	Wood (B)	8 cm x 12 cm x 2 cm

b. Construction

(1) Test Tube Rack

Drill 12 holes, 2.2 cm in diameter at evenly spaced intervals in one of the larger pieces of wood (A) to form the top of the rack.

Secure the sides (B) to the top (A) as shown, with nails or cement. Secure the bottom (A) in place with nails or cement.

c. Notes

(i) For larger or smaller test tubes, the dimensions may be varied.

V. GLASSWARE AND CROCKERY

A. GLASSWARE

This section describes the construction of various items of laboratory glassware. The chief activity in making these is glass cutting, which is described in detail in a separate section. Refer to GLASSWARE TECHNIQUES AND ACCESSORIES (I) for specific direction for cutting and working glass.

B. CROCKERY

Included in this section is one item composed of concrete.

A. GLASSWARE

A1. Light Bulb Glassware *

a. Materials Required

Components	Qu	Item Required	Dimensions
(1) Flask or Test Tube	1	Clear Incandescent Light Bulb (A)	Varies

b. Construction

(1) Flask or Test Tube

Sawing

Secure a hacksaw blade in a vise. Hold the bulb (A) horizontally, and wrapped in cloth for safety. Cut around the edge of the base near the terminals. Remove the end thus cut.

*Adapted from C. S. Rao (Editor), Science Teachers' Handbook, (Hyderabad, India: The American Peace Corps, 1968), pp 146-147.

With a triangular file, puncture the inner seal and remove all the parts from inside the bulb. Smooth cut edge with emery paper or the file.

Heat cutting

Wrap a piece of tape around the neck of a clear bulb (A), about 0.3 cm from the base, as a cutting guide. With a triangular file or glass cutter, make a continuous scratch all the way around the neck of the bulb.

Remove the tape, and use the electric bottle cutter (I/F2) to heat the scratch until the bulb cracks all the way around. Discard the base and internal components.

Wrap the lower portion of the bulb in cloth to protect the hands. Hold the cut edge in a gas or alcohol burner flame until the edge softens and curls back upon itself to form a smooth lip.

c. Notes

(i) The average 150 watt bulb forms a flask of about 150 ml capacity, the average 200 watt bulb a flask of about 200 ml capacity

(ii) Bulbs of 100 watts or less may be used for test tubes.

(iii) Small test tubes may also be made from glass medicine vials or discarded antibiotic ampules.

(iv) The bulb is made of thin enough glass to be heated safely while containing a liquid.

(v) The glassware made from light bulbs requires special supports to hold it upright. Consult the section on Supports, Stands, and Holders (IV) for suggestions.

A2. Beaker

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Beaker	1	Wide-bottom Jars or Bottles (A)	Varies

b. Construction

(1) Beaker

Cut off the bottom portion of jars or bottles (A) to make beakers of various sizes (I/F2). Smooth the rough edge by filing with emery paper or a file.

c. Notes

(i) Since bottles and jars are generally made of soft glass, rather than hard, heat resistant glass; beakers made from bottles or jars cannot be used for hot substances or for substances that are to be heated. When heated, they will break.

A3. Funnel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Funnel	1	Glass Bottle (A)	Varies

b. Construction

(1) Funnel

Cut off the top portion of narrow-mouthed glass bottles (A) to make funnels of various sizes (I/F2).

A4. Bell Jar

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Jug	1	Glass Jug or Carboy (A)	4-8 liters
	1	Rubber or Cork Stopper (B)	To fit Jug (A)

b. Construction

(1) Jug

Cut off the bottom of the glass jug or carboy (A). Sand the cut edge smooth with emery paper. Seal the neck of the jug with the stopper (B).

A5. Watch Glass

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Watch Glass	1	Light Bulb (A)	Varies

b. Construction

(1) Watch Glass

Carefully cut the tops off old light bulbs (A) to make watch glasses of various sizes. Smooth the cut edges by fire polishing.

c. Notes

(i) The watch glass is commonly used to hold small quantities of a solution fror which crystals are to be collected.

A6. Petri Dish

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Petri Dish	1	Wide-bottom Bottles or Jars (A)	Varies

b. Construction

(1) Petri Dish

Cut off the bottom of a wide-bottom glass bottle or jar (A). Make as many as needed. Smooth the rough edge with emery paper.

c. Notes

(i) Jar lids or aluminum foil make satisfactory tops for these dishes. Waxed paper or cardboard dipped in wax also make suitable covers.

(ii) Petri dishes are often used to hold small quantities of a liquid from which crystals are to be collected.

(iii) They may also be used to contain food or culture media for growing bacteria, fungi, or molds. When petri dishes are used for culturing purposes, they must be used with lids and must be sterilized (BIOL/VII/A2).

A7. Wash Bottle

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Glass or Plastic Bottle (A)	Approximately 250 ml capacity
	1	2-Hole Stopper (B)	To fit container (A)
(2) Delivery Tube	1	Glass Tubing	Approximately 0.5 cm diameter, and at least 20 cm longer than height of container.
(3) Mouthpiece	1	Glass Tubing (D)	About 0.5 cm diameter, and shorter than delivery tube.

b. Construction

(1) Container

Select a glass or plastic bottle with a narrow neck and a capacity of about 250 ml or larger (A).

Fit the container (A) with a two-hole stopper (B).

(2) Delivery Tube

Make a nozzle (I/D3) at one end of the long glass tube (C). Fire polish both the nozzle and the other end and let the tube cool. Next, bend the tube, about 8 - 10 cm from the nozzle end at a sharp angle as shown. When it is cool, carefully push the tube into the stopper (B) so that it extends to within 0.5 cm of the bottom of the container. Trim to the correct length, if necessary, and fire polish the end.

(3) Mouthpiece

Fire polish both ends of the glass tube (D). About 8 - 10 cm from one end, make a wide-angled bend. When the tube has cooled, push it carefully into the stopper (B). Insert the stopper into the container (A).

c. Notes

(i) To use the wash bottle, fill it with (distilled) water. Direct the delivery tube in the desired direction and blow through the mouthpiece to force water through the nozzle in a fine stream.

(ii) If a soft plastic squeeze bottle is used, only the delivery tube and a one-hole stopper are necessary. Squeeze the bottle to force water out the nozzle.

A8. Aspirator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Glass Bottle (A)	4-8 liter capacity
	1	2-Hole Rubber Stopper (B)	To fit Bottle (A)
(2) Intake Tube	1	Glass Tubing (C)	0.5 cm diameter, approximately 15 cm long
	1	Glass Tubing (D)	0.5 cm x 10 cm
	1	Plastic or Rubber Tube (E)	Approximately 1.0 cm diameter, 35 cm long
	1	Screw Clamp or Pinch Clamp (F)	(IV/A4 and A5)
(3) Outlet Tube	1	Glass Tube (G)	0.5 cm diameter, 10 cm longer than height of bottle
	1	Glass Tube (H)	0.5 cm x 10 cm
	1	Plastic or Rubber Tube (I)	Approximately 1.0 cm diameter, 35 cm long

	1	Screw Clamp or Pinch Clamp (J)	(IV/A4 or A5)
(4) Drain Tube	1	Plastic or Rubber Tube (K)	Approximately 1.0 cm diameter, 20 cm long
	1	Screw Clamp or Pinch Clamp (1)	(IV/A4 or A5)

b. Construction

(1) Container

Fit the bottle (A) with a two-hole rubber stopper (B). Carefully bore a hole approximately 1.0 cm in diameter, 2 cm from the bottom of the bottle.

(2) Intake Tube

Make a 90° bend about 5 cm from one end of the longer glass tube (C). Insert this tube into one of the holes in the stopper of the bottle. Fit the other end of the tube into the plastic or rubber tubing (E). Insert the short glass tube (D) into the open end of the plastic or rubber tubing (E).

Construct a screw clamp or pinch clamp (F) (IV/A4 or A5) to close the tubing (E).

(3) Outlet Tube

Make a 90° bend about 5 cm from one end of the longer glass tube (G). Insert this tube into one of the holes of the rubber stopper (B) such that the straight section of the tube reaches within 2 cm of the bottom of the bottle as illustrated.

Attach the plastic or rubber tubing (I) to the other end of the glass tube (G). Fit the shorter glass tube (H) into the free end of the tubing (I) and close it with a clamp (J).

(4) Drain Tube

Insert the plastic or rubber tubing (K) into the hole in the side of the container extending it 1 - 2 cm inside the bottle. Seal the tubing (K) in the hole with epoxy resin. Close the tube with a clamp (L).

c. Notes

(i) This item may be used to collect gas by water displacement. First, the bottle is filled with water and all three tubes are closed with clamps. The intake tube is then attached to the gas generator and the outlet tube is directed into a drain or waste receptacle. When both the intake and outlet tubes are opened (drain tube remains closed) gas will enter the bottle, and displaced water will be forced out through the outlet tube.

(ii) The aspirator may also be used to provide suction to aid in filtration. Again, the bottle is filled with water, and all three tubes are closed with clamps. The intake tube is connected to the suction tube of a suction-filter flask (VI/A4). The drain tube is directed into a drain or waste receptacle. The liquid to be filtered is poured into the filter funnel (fitted with filter paper), and the intake and drain tubes are opened. The outlet tube remains closed. The flow of water from the aspirator bottle creates a negative pressure that tends to increase the rate of filtration in the suction filtration apparatus.

B. CROCKERY

B1. Mortar and Pestle

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Mortar	0.5 kg	Sand (A)	Fine grain
	1.5 kg	Cement (B)	--
	1	Tin Can (C)	Capacity approximately 0.5 kg
	0.5 kg	Modeling Clay (Plasticine) (D)	--
	1	Wire Mesh (E)	10 cm x 10 cm
	1	Epoxy Glue (F)	--
	1	Light Bulb (G)	100 watts
(2) Pestle	1	Light Bulb (H)	60 watts
	1	Epoxy Glue (I)	--
	1	Nail (J)	Approximately 10 cm long

b. Construction

(1) Mortar

Cross Section

Cut the tin can (C) in half. Pack the modeling clay (plasticine) (D) into the bottom half of the can. Then mold the clay into the external shape of the mortar. Make the bottom of the clay mold smooth and flat, as this will be the bottom of the mortar.

Make a mixture of 3:1 cement (B)/ sand (A). Add water to make a thick concrete paste. Next, cover the mold with a 2 - 3 cm layer of concrete (A and B). Cut the wire mesh (E) into 2 cm wide strips and press the strips on the coating of concrete. Cover the entire surface of concrete with the screening strips (E).

Fill the remaining space with concrete. Cover the 100 watt light bulb (G) with oil and press it halfway into the mold. Scrape away and discard any concrete that overflows the mold. Level off the top of the concrete.

Take a thin wooden or metal rod and push it in and out of the concrete around the bulb (G), touching the bulb. Break up, in this way, any air bubbles between the bulb and the concrete.

Allow at least 24 hours or more for the concrete to dry. Then cut away the can with a can opener and tin snips and peel

away the clay mold. Break and remove the bulb, taking care to remove all pieces of broken glass. Place the mortar in a large can or crock and cover it with water. Allow it to soak for three weeks in order to cure. Add water to the container as it is absorbed by the mortar.

When the mortar has cured, remove it from the water and allow it to dry. Then cover the entire surface with epoxy glue (F) to seal the concrete, fill air bubbles, and provide a smooth grinding surface.

(2) Pestle

Cut the metal tip off the 60 watt light bulb (H) with a hacksaw. Remove the insides. File the cut edges smooth with a round file.

Support the bulb upright in a container of sand or appropriate stand and fill the entire bulb with the concrete paste (A and B). Insert a nail almost all the way to the bottom of the bulb, to provide support for the concrete.

Allow the concrete to dry (at least 24 hours). Break the glass glass, leaving the metal end intact. Cure the pestle immersed in water for three weeks. Remove, dry, and coat with epoxy

glue (I), making sure all air bubbles are filled.

c. Notes

(i) The mortar and pestle are used to grind crystals or lumps of substances into powder. The substance to be ground is placed in the mortar, and ground with the pestle to the desired consistency.

(ii) If the epoxy-coated grinding surfaces of the mortar and pestle become worn away with use, clean them and reapply a layer of epoxy glue to provide a smooth surface.

VI. SEPARATORS AND PURIFIERS

This section on separators and purifiers has been divided into four subsections:

A. MECHANICAL SEPARATORS

These are devices for separating solid/solid, liquid/solid, or solid/liquid mixtures. Included are magnets, sieves, filtration apparatus, and separatory funnels.

B. DISTILLATION APPARATUS

These devices are used for separating liquid solutions and include several types of distillation apparatus.

C. ELECTRICAL SEPARATOR

This device is used in the electrolytic separation of substances and to demonstrate Faraday's quantitative laws of electrolysis.

D. CENTRIFUGAL SEPARATORS

Centrifugal separators are used to cause the rapid precipitation of materials in suspension.

A. MECHANICAL SEPARATORS

A1. Magnets

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Bar Magnet	1	Bar Magnet	PHYS/IX/A1, Notes

b. Construction

(1) Bar Magnet

Purchase a magnet, or magnetize a steel bar according to the instructions described in PHYS/IX/A1, Notes.

c. Notes

(i) Magnets are used to separate ferromagnetic materials from other materials, such as dirt or sand.

(ii) Magnets in a variety of shapes, materials, and field strength may be purchased from commercial sources and may be used in place of the bar magnet above.

A2. Cone Sieve

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cone Sieve	1	Wire Mesh (A)	Approximately 7 cm x 7 cm
	1	Thin Wire (B)	Approximately 10 cm

b. Construction

(1) Cone Sieve

Cut a circle from the wire mesh (A). Then cut out and remove a segment of the circle as shown.

Roll the wire mesh into the shape of a cone, overlapping the edges slightly. Thread the thin wire (B) in and out of the wire mesh, at the overlapped edges, to hold them together.

c. Notes

(i) This cone may be made larger or smaller by varying the dimensions of the wire mesh used.

(ii) Material suitable for replacing the wire mesh may be made by dipping a cloth having a very coarse weave into melted wax, varnish, or starch.

(iii) Sieves are suitable for grading small particles or washing small amounts of materials under a stream of water.

A3. Basket Sieve

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basket	1	Wire Mesh (A)	Approximately 30 cm x 40 cm
	4	Thin Wire (B)	Approximately 20 cm
(2) Frame	1	Stiff, Heavy Wire (C)	Approximately 4 cm diameter, 80 cm long
	1	Thin Wire (D)	Approximately 80 cm long
(3) Handle	1	Wood (E)	2 cm x 2 cm x 15 cm

b. Construction

(1) Basket

Cut the wire mesh (A) according to the pattern shown, and discard the shaded portions. Then fold all the flaps up along the dashed lines. Overlap the cut edges slightly, and thread the thin wires (B) in and out of the wire mesh at the overlapped edges to hold them together.

(2) Frame

Bend the heavy wire (C) as shown, to fit the dimensions of the top of the basket. Allow an extension of 8 - 9 cm to fit into the handle (E).

Fold the top 1 cm of the basket around the frame to the inside, and lace the thin wire (D) in and out of the basket mesh to secure the frame in place.

(3) Handle

Drill a hole approximately 0.8 cm in diameter and approximately halfway through the length of the wooden handle (E).

Insert the straight section of the frame into this hole in the handle, and cement it in place.

c. Notes

(i) This basket sieve may be made larger or smaller by varying the dimensions of the wire mesh, frame, and handle used.

(ii) This sieve is used just as the funnel sieve in the preceding section, but for larger amounts of material.

A4. Suction-Filter Flask

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Flask	1	Glass Bottle (A)	Capacity 250-500 ml
	1	1-Hole Rubber Stopper (B)	To fit bottle (A)
	1	Glass Tube (C)	0.5 cm diameter, 6 cm long
(2) Funnel	1	Funnel (D)	V/A3
	1	1-Hole Rubber Stopper (E)	To fit neck of funnel (D)
	1	Filter Paper (F)	Approximately 15 cm diameter
(3) Suction Tube	1	Rubber Tube (G)	1.0 cm diameter, 15 cm long
	1	Glass Tube (H)	0.7 cm diameter, 10 cm long

b. Construction

(1) Flask

Bore a hole (I/E2) just slightly smaller than 1.0 cm in diameter in the side of the bottle (A) near the top. Insert the glass tube (C) into the rubber stopper (B) so that approximately half the tube protrudes from the top of the stopper. Fit the stopper into the mouth of the bottle.

(2) Funnel

Insert the protruding end of the glass tube into the stopper (E) for the funnel (D). Push the two stoppers together, and fit the funnel stopper into the neck of the funnel (D).

(3) Suction Tube

Insert the rubber tubing (G) into the hole in the side of the bottle so that about 1 cm of tubing is inside the bottle. Seal the tubing in place with eqoxy resin. Insert a short piece of glass tubing (H) into the open end of the rubber tubing.

c. Notes

(i) A circle of filter paper is folded as illustrated and placed in the funnel. The suction tube is then connected to the water-filled aspirator (V/A8). The material to be filtered is placed in the filter paper in the funnel. Water is then allowed to drain from the aspirator. The partial vacuum thus formed will draw air from the flask, and air on the outside will be drawn through the funnel, causing more rapid filtration to occur.

(ii) Filter paper is available from commercial suppliers, but substitutes include paper towels, blotting paper, or cotton.

A5. Separatory Funnel

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Funnel	1	Glass Bottle (A)	Capacity 250-500 ml
	1	Rubber Stopper (B)	Approximately 2 cm diameter (large end)
(2) Delivery Tube	1	1-Hole Rubber Stopper (C)	To fit bottle (A)
	1	Glass Tubing (D)	0.7 cm diameter, 15 cm long
	1	Rubber Tubing (E)	1 cm diameter, 8 cm long
	1	Wooden Pinch Clamp (F)	IV/A4

b. Construction

(1) Funnel

Select a clear glass bottle (A) with a tapered, narrow neck. Drill a hole in the bottom of the bottle and enlarge it sufficiently to receive the rubber stopper (B). Smooth the rough edge with emery paper before sealing.

(2) Delivery Tube

Heat the glass tubing (D) with a burner and draw it out near one end and cut as shown to leave a 5 cm long nozzle and a 5 cm long connector. Carefully fire polish all cut edges.

Fit the glass connector into, but not through, the one-hole rubber stopper (C). Insert the other end into the rubber tubing (E), and connect the rubber tubing to the nozzle. Fit the stopper into the neck of the bottle.

Construct a wooden pinch clamp (IV/A4) and use it to close the rubber tubing.

c. Notes

(i) The separatory funnel is used to separate two liquids that do not mix. With the delivery tube closed, the mixture of liquids is poured into the funnel through the hole at the top, (bottom of bottle). The funnel is then sealed and shaken vigorously for several seconds. Then the funnel is secured in a ring stand (IV/B4) or other appropriate support and allowed to rest undisturbed until the liquids separate into layers. The lower liquid is then drained through the delivery tube by opening the pinch clamp. In order to allow the funnel to drain properly, the stopper must be removed from the top.

(ii) A glass bead just slightly larger than the internal diameter of the rubber tubing may be used in place of the pinch clamp. Push the bead into the rubber tubing before inserting the glass nozzle. The bead will seal the rubber tube. To dispense liquid from the funnel, squeeze the tube between thumb and forefinger at the location of the bead.

Cross Section

B. DISTILLATION APPARATUS

B1. Simple Distillation Apparatus

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Distilling Flask	1	Flask (A)	Capacity approximately 200 ml
	1	1-Hole Rubber Stopper (B)	To fit flask (A)
(2) Delivery Tube	2	Glass Tubing (C)	0.7 cm diameter, 5 cm long
	1	Rubber or Plastic Tubing (D)	1 cm diameter, approximately 60 cm long
(3) Collecting Flask	1	Flask or Bottle (E)	Capacity approximately 200 ml

b. Construction

(1) Distilling Flask

Fit the light bulb flask (A) or other flask with the one-hole rubber stopper (B).

(2) Delivery Tube

Support the flask in a stand, (IV/B4, B5, or B6).

Insert a short piece of glass tubing (C) into the stopper in the flask. Attach the other end of the glass tube to a long piece of rubber or plastic tubing (D). Insert another short piece of glass tubing (C) into the other end of the rubber or plastic tubing.

(3) Collecting Flask

Place a flask (E) or jar in a bowl or pan of cool water and lead the free end of the delivery tube into the flask.

c. Notes

(i) A sample of a liquid--impure water, for example--to be distilled is placed in the distilling flask, and the stopper is inserted into the flask. The liquid is heated until it boils. As the liquid boils, its vapor travels through the delivery tube and is cooled enough by air surrounding the tube to condense and drip into the collecting flask. The water in the bowl helps cool the condensed liquid still more, as it is quite hot when first collected.

(ii) This simple apparatus is ideal for student participation in simple distillation operations involving small volumes of liquids.

B2. Condenser

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Stand	2	Wood (A)	18 cm x 15 cm x 1 cm
	1	Wood (B)	25 cm x 15 cm x 1 cm
	2	Nails (C)	3 cm long
	2	Rubber Bands (D)	5 cm x 9 cm
(2) Water Jacket	1	Plastic or Glass Bottle (E)	Capacity approximately 1-2 liters
	1	1-Hole Rubber Stopper (F)	To fit bottle (E)
	2	Rubber Tubing (G)	1 cm diameter, 3 cm long
	2	Glass Tubing (H)	0.7 cm diameter 10 cm long
(3) Condensing Tube	1	Glass Tubing (I)	0.7 cm diameter, 10 cm longer than bottle

c. Construction

(1) Stand

Trace around the base of the bottle (E) on the larger piece of wood (B) as shown. Cut along the traced line.

In a similar fashion, make a small semicircular cutout to accommodate the neck of the bottle (E) in one of the smaller pieces of wood (A).

Nail the two sections with cutouts to the third (A) to form the stand. Drive a nail (C) into each upright to anchor the rubber bands (D) that hold the water jacket in place.

(2) Water Jacket

Take a plastic bottle (E) if possible, a glass bottle if necessary. Drill three holes approximately 1 cm in diameter in the bottle as illustrated.

(3) Condensing Tube

Fit each short piece of glass tubing (H) into a piece of rubber tubing (G). Insert each piece of rubber tubing into one of the holes in the side of the bottle. Seal with epoxy resin if necessary to make sure that the seal is watertight.

Fit the mouth of the bottle with a one-hole rubber stopper (F).

Insert a long glass tube (I) through the hole in the base of the bottle, all the way through the bottle, and through the rubber stopper to the outside again.

Rest the bottle in the stand with the base higher than the neck and the inlet tube below the outlet tube. Loop the rubber bands (D) around the base and neck of the bottle to secure it in position.

c. Notes

(i) To use this condenser, fasten a rubber or plastic tube from the flask in which a liquid is being boiled to the upper end of the condensing tube (that end protruding from the bottom of the bottle). Another tube, from a cold water source, is connected to the inlet (lower) tube, and a third rubber or plastic tube is attached to the outlet and led to a drain. As hot gas flows through the condensing tube, it is cooled by the water jacket and condenses, to drip as a liquid from the lower end of the condensing tube where it can be collected in a beaker.

B3. Water Still

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame Support	4	Wood (A)	4 cm x 5 cm x 25 cm
	1	Wood (B)	2 cm x 16 cm x 25 cm
(2) Water Jacket	2	Metal Strapping (C)	1.5 cm x 28 cm
	1	Large Tin Can (D)	Capacity approximately 1-1.5 kg
	2	Rubber Tubing (E)	1 cm diameter, 5 cm long
	2	Glass Tubing (F)	0.7 cm diameter, 5 cm long
(3) Condensing	1	Copper Pipe (G)	1 cm outside diameter, 5 cm longer than can height
	1	1-Hole Rubber Stopper (H)	Approximately 2.5 cm diameter (large end)

1 Glass Tubing (I) 0.7 cm diameter, 5 cm long

b. Construction

(1) Frame Support

Nail two pieces of wood (A) to a flat piece (B) to form a base and uprights. Then nail two more pieces of wood (A) to the outsides of the uprights, as shown, to form supports for the can.

(2) Water Jacket

Cut a hole approximately 2 cm in diameter in the center of the bottom of the can (D). Crimp the cut edges inward. Cut a smaller hole, not quite 1 cm in diameter, in the side of the can near the bottom, to accommodate the inlet tube. Cut another small hole, not quite 1 cm in diameter, in the side of the can near the top, for the outlet tube.

Insert each short piece of glass tubing (F) into a short piece of rubber tubing (E). Insert each rubber tube into one of the two small holes in the can. If the rubber tubes do not fit snugly by themselves, make a watertight seal with candle wax or epoxy resin.

Set the can in place in the frame support. To secure it in position, nail two pieces of strapping (C) to the frame support, one on each side of the can.

(3) Condensing Pipe

Choose a one-hole rubber stopper (H) that tightly seals the hole in the bottom of the water jacket can. Insert a short piece of glass tubing (I) part way through the stopper, from the large end. Insert the copper pipe (G) into the stopper from the other end.

Insert the condensing pipe into the water jacket can through the hole in the bottom of the can. Push the stopper tightly into the hole from the outside. Seal with candle wax or epoxy resin, if necessary, to produce a watertight seam.

c. Notes

(i) A plastic or rubber tube from a water source is attached to the inlet tube, and another tube is attached to the outlet tube and led to a drain. A plastic or rubber tube from the container in which water is boiled is connected to the free end of the copper condensing pipe. Water vapor flowing through this tube will condense and drip from the glass delivery tube at the bottom of the still, where it can be collected.

(ii) This still is suitable for continuous operation, in order to produce distilled water for class use. In such a case, a large kettle should be used for boiling the water, and a plastic or rubber tube can be attached to the delivery tube and led to a storage container.

(iii) The size of the frame support for this still is determined by the size of the can used for the water jacket. Its dimensions will vary, according to the size of the can used.

C. ELECTRIC SEPARATOR

C1. Electrolysis Apparatus

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Glass Jar (A)	Approximately 100-200 ml capacity
(2) Electrodes	2	Stiff Wire, Insulated (B)	Approximately 0.1 cm diameter, 25 cm long
	2	Thin Copper Sheet (C)	1.5 cm x 3.0 cm
	2	Masking or Adhesive Tape (D)	2 cm x 4 cm
(3) Collecting Tube	2	Test Tubes or Vials (E)	Approximately 1.5 cm diameter, 10 cm long
(4) Frame Support	2	Wood Strips (F)	0.2 cm x 2 cm x 15 cm
	2	Wood Blocks (G)	Approximately 2 cm x 2 cm x 1.3 cm
	2	Rubber Bands (H)	Approximately 0.2 cm x 4 cm

b. Construction

(1) Container

Choose a small glass jar (A) with a capacity of 100 - 200 ml, or cut off the top of a jar to

make a container of appropriate size.

(2) Electrodes

Strip about 1.5 cm of the insulation off each end of the stiff, insulated wire (B). Solder one end of each wire to a piece of the copper sheet (C), as shown.

When the solder has cooled, roll the copper sheet (C) into a spiral plate.

Bend each of the stiff wires (B) as illustrated. Make the large loop long enough to fit over the lip of the container (A) when the flat 2 cm portion of the wire is resting on the bottom of the container.

Place the electrodes at opposite sides of the container. Adjust the bends, if necessary, so that the plates of the electrodes are about 1 cm apart. Secure the wires to the outside of the container with tape.

(3) Collecting Tubes

For the collecting tubes (E), use small glass or plastic test tubes or vials that are slightly taller than the height of the container (A).

(4) Frame Support

For the frame support, use two thin, flexible wooden strips (F) about twice as long as the diameter of the container. Cut two small wooden blocks (G) just slightly narrower than the diameter of the collecting tubes.

Glue the two blocks to one of the strips, about 5 cm apart.

Glue the other strip to only one of the blocks, as shown.

Hold the rubber bands (H) aside until the apparatus has been set up [see Note (i)].

c. Notes

(i) This apparatus is used to separate water into oxygen and hydrogen, which are collected in the tubes. The container is filled with water sufficient to cover the terminals by less than 1 cm. A little vinegar or washing soda ($Na_2CO_3 \cdot 10H_2O$) is added to the water to increase its conductivity. The collecting tubes are filled with the same acidic (vinegar) or basic (Na_2CO_3) solution. Then, with the open end sealed with a thumb or forefinger, each tube is inverted and placed into the container. The open end of the tube must be placed below the surface of the solution before it is uncovered. Then, without being lifted out of the solution, each tube is placed over one of the electrodes.

The frame support may be placed around the two collecting tubes. It is secured tightly around the tubes with rubber bands at each end. With the tubes

thus supported, the frame is rested on the top of the container and the tubes are carefully adjusted so that the open ends do not rest on the bottom of the container, but are about 1 cm above the bottom and below the surface of the solution in the container.

When the free ends of the electrodes are connected to three or more 1.5 volt cells connected in series, sufficient current passes through the solution to break down the water. Hydrogen is the gas generated at the negative plate (cathode) and collected in the tube placed over that plate. Oxygen is generated at the positive plate (anode) and is collected approximately one half as rapidly as hydrogen.

(ii) This apparatus is quite suitable for student use in the laboratory, as it is simple to set up and requires little current. With three or more 1.5 volt cells, the gases are evolved rapidly and the tubes can be filled in about 20 - 30 minutes.

(iii) Several factors enhance the efficient operation of this apparatus. The small volume of solution used and the proximity of the plates reduce the amount of resistance in the system and allow it to function on low current. If the plates are cleaned after each use, the apparatus will also function more efficiently.

D. CENTRIFUGAL SEPARATORS

D1. Hand Drill Centrifuge

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Horizontal Bar	1	Wood (A)	2 cm x 2 cm x 32 cm
(2) Test Tube Holder	2	Stiff Wire (B)	Approximately 0.2 cm diameter, 30 cm long
(3) Shaft	1	Nail (C)	0.5 cm diameter, 18 cm long
	1	Bolt (D)	Approximately 0.5 cm diameter, 2 cm long

b. Construction

(1) Horizontal Bar

0.4

0.4

Drill holes, approximately 0.4 cm in diameter, at each end of the wooden bar (A). Drill a hole through the center of the bar, as shown. Make the diameter of this hole slightly smaller than the diameter of the nail (C) used for the shaft.

Then, drill a hole perpendicular to and intersecting the hole in the center of the bar. Make the diameter of this hole slightly smaller than the diameter of the bolt (D) used to hold the shaft in place.

(2) Test Tube Holder

Take a test tube of the size that will be used in the centrifuge. Wind one piece of heavy, stiff wire (B) (coat hanger wire, for example) around the test tube two or three times. Make the coil very snug around the test tube so that the test tube lip will not slip through it. Leave a straight portion of about 8 - 9 cm at the top of the coil.

Bend the straight portion of the wire at an angle to the rest of the coil as shown. About 3 cm from the coil, bend the wire again, at right angles to the upright portion.

Fit the free end of the wire into one of the end holes in the horizontal bar. Check to see that the fit is loose enough for the holder to swing easily. Then bend the excess wire down, as shown, to secure the holder in the horizontal bar.

Repeat this procedure for the construction of the second test tube holder.

(3) Shaft

Carefully thread the short bolt (D) into the center, horizontal hole in the horizontal bar. Then unscrew it halfway. Fill the nail hole (vertical hole) with epoxy glue and tap the nail (C) into the hole. Tighten the bolt against the nail and coat the threads of the bolt with epoxy glue.

c. Notes

(i) A precipitate formed by a chemical reaction in a test tube will eventually settle to the bottom because of the force of gravity acting upon it. The time required for a given precipitate to settle is dependent on several factors; among these are the volume, density, and particle size of the precipitate. Spinning such material in a test tube in a centrifuge reduces this duration by creating a strong centrifugal force, which causes the heavier precipitate to settle to the

outside of the centrifuge. When the test tube holders are free to pivot outward, as in this centrifuge, the test tubes will assume a nearly horizontal position when the centrifuge is in rapid motion. Thus, the bottom of the test tube becomes the "outside" of the centrifuge, and precipitate is pulled to the bottom of the tube.

(ii) To use this centrifuge, place an appropriately sized test tube containing material to be centrifuged through one of the wire holders. To balance the centrifuge, place a test tube with an equal volume of water in the other holder. Take care to insure that the test tubes are securely held in place by the holders. Seal both test tubes with corks or stoppers to prevent spillage. Fix the end of the shaft firmly in a hand drill. Clamp the drill handle tightly in a heavy vise, stand at arm's length from the drill, and turn the handle of the drill. The centrifuge will spin, causing the precipitate to collect at the bottom of the test tube. To stop the centrifuge, let go of the drill handle and allow the centrifuge to continue to spin until it comes to a gentle stop. Another way to stop the centrifuge is to turn the drill handle more and more slowly until it is brought to a gentle stop. Sudden stops, which will shake up the precipitate, are to be avoided.

(iii) If a vise is not available, the drill may be held at arm's length from the body while the centrifuge is spun.

(iv) This centrifuge is capable of being spun at 300 - 500 revolutions per minute. It was tested with several precipitates, such as $CaCO_3$ and $AgNO_3$, and was found to reduce settling time from several hours (gravity) to less than one minute.

(v) This centrifuge, whether clamped in a drill or held at arm's length, must be used with extreme care since the test tubes swing close to the user. A safer, more permanent centrifuge, which incorporates this centrifuge as its rotating assembly, is described in the following section.

D2. Centrifuge

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	4 cm x 9 cm x 30 cm
	3	Wood (B)	2 cm x 5 cm x 30 cm
	2	Wood (C)	2 cm x 5 cm x 25 cm

	1	Wood (D)	Approximately 3 cm x 3 cm x 1 cm
(2) Wheel	1	Wood (E)	1 cm x 15 cm x 15 cm
	1	Wooden Spool (F)	Approximately 3 cm x 3 cm x 3 cm
	2	Washers (G)	Approximately 0.8 cm inside diameter, 2.0 cm outside diameter
	1	Screw (H)	Approximately 0.6 cm diameter, 6.0 cm long
	1	Screw (I)	Approximately 3 cm long
	1	Rubber Strip (J)	1 cm x 50 cm
(3) Axle	1	Wood (K)	4 cm x 4 cm x 16 cm
	1	Wooden Spool or Dowel (L)	3 cm diameter, 3.5 cm long
	3	Finishing Nails (M)	Approximately 5 cm long
	1	Screw (N)	Approximately 0.6 cm diameter, 6.0 cm long
	2	Washers (O)	Approximately 0.8 cm inside diameter, 1.5 cm outside diameter
	1	Nail (P)	0.5 cm diameter, 18 cm long
	1	Bolt (Q)	Approximately 0.5 cm diameter, 2 cm long
	1	Rubber Strip (R)	3.5 cm x 10 cm
	2	Metal Strapping (S)	11 cm x 1 cm
(4) Head	1	Wood (T)	2 cm x 2 cm x 32 cm
	2	Stiff Wire (U)	Approximately 0.2 cm diameter, 30 cm long
	1	Bolt (V)	Approximately 0.5 cm diameter, 2 cm long

b. Construction

(1) Base

With nails or glue and screws, secure the thick piece of wood (A) to two pieces of wood (B) as shown to form the feet and bottom of the base. Drill a hole approximately 0.5 cm in diameter at each end of the feet (B).

Next, nail or glue and screw the third piece (B) to the bottom of the base, in an upright position as shown. Secure the two shorter uprights (C) in position as shown. Glue the small piece of wood (D) to the center of the horizontal board. When the glue has dried, drill a hole about 0.5 cm in diameter through the small piece of wood (D) and a centimeter or so into the base (A).

(2) Wheel

Wood (E)

Inscribe a circle in the thin wooden square (E). Carefully cut out the circle. Drill a hole, 0.7 cm diameter, through the center of the circle.

Fasten the strip of rubber sheeting (J) (e.g., from a tire inner tube) to the circumference of the wheel with glue and small nails with heads.

With the shorter screw (I), fasten the wooden spool (F) loosely to the wheel about halfway between the center and edge of the wheel. The handle must be free to rotate around the screw.

Mount the wheel to the base by inserting the long screw (H) through a washer (G), through the wheel, then through the second washer (G). The holes in the wheel and washers should be slightly larger in diameter than the screw (H). Finally, turn the screw firmly into the small piece of wood (D) on the horizontal board of the base. Make certain that the wheel will rotate freely around the screw without wobbling.

(3) Axle

For the upper section of the axle, use the wooden block (K) or dowel. Drill a hole approximately 0.4 cm in diameter and approximately 5 cm deep into the center of one end of the block. Then drill a second hole, about 2.5 cm from the end, at a right angle to and intersecting the first hole. Make the hole about 0.4 cm in diameter, or just a little smaller than the bolt (Q) which is to be threaded into it.

Flatten the end of a large nail (P) by hammering it on a metal block or anvil.

Carefully thread the bolt (Q) as far as possible into the bolt hole in the axle, then unscrew it halfway. Fill the nail hole with epoxy glue, and tap the nail (P) into the hole. Tighten the bolt against the nail, then coat its threads with epoxy glue. Finally, cut the head off the nail.

For the lower section of the axle, use a wooden spool (L) from which the thread has been removed, or a 3 cm diameter dowel. Cut the spool or dowel to a height of about 3.5 cm. Fasten a strip of rubber sheet (R) around the outside, just as for the wheel. Enlarge the hole in the spool to about 0.7 cm diameter.

Fit one washer (O) on the top of the spool, aligning the holes of spool and washer. Drive three small finishing nails (M) into the top of the spool, outside the washer. Let approximately 3 cm of nails protrude from the top of the spool, and cut off their heads.

Overhead View of Base, Wheel and Axle Location

Locate the position of the axle by setting the spool on the horizontal board (A) of the base such that the rubber strip on the spool presses firmly against the rubber strip on the wheel. Mark the position of the center of the spool, and drill a small hole at that position.

Mount the spool (L) on the horizontal board (A) of the frame by passing a long screw (N) through the washer (O) and spool (L); then through a second washer (O), and into the hole in the base. Turn the screw firmly into the horizontal board, so that the spool is free to rotate. In addition, the edge of the wheel must rub the edge of the spool firmly enough so that when the wheel turns, the spool also rotates.

Construct strapping braces for the axle as follows: Drill a hole 0.8 cm in diameter in the center of one of the pieces of metal strapping (S). Nail this piece to the two shorter uprights (C) of the base such that the hole in the strapping is directly over the center of the spool on the base below. Drill a similar hole near one end of the other piece of strapping (S), and nail it, as shown, to the taller upright of the base (B) such that its hole is directly over the hole in the strapping below it. Trim off any excess.

Slip the nail end of the upper section of the axle through the holes in the strapping braces. Rest the other end of the upper section evenly on the tops of the three nails in the spool, and then drive the upper section into the nails with a hammer so that the spool and upper section will form a continuous solid piece. However, do not drive the upper section so far down that its end will hit the top of the screw and prevent the entire axle from turning. If this operation has been done correctly, the axle will turn when the wheel is rotated.

(4) Head

Prepare the horizontal bar and test tube holders according to directions given for the Hand Drill Centrifuge, VI/D1, using the wood (T) and stiff wire (U). Secure the nail of the axle to the centrifuge head according to directions given in VI/D1 with the bolt (V).

c. Notes

(i) The centrifuge should be bolted or clamped to the table top before using.

(ii) To use this piece of apparatus, the substance to be centrifuged is placed in an appropriately sized test tube. A second test tube is filled with an equal amount of material to be centrifuged or an equal volume of water. Each test tube is placed in one of the holders and checked to see that they will not slip out through the holder. Both test tubes are sealed with stoppers. Stand at arm's

length from the centrifuge and turn the wheel, first slowly, then more and more rapidly. The tubes will be spun about in a nearly horizontal position. Do not try to stop the centrifuge suddenly by holding the wheel stationary; either let go of the wheel and allow the centrifuge to come to a gentle stop, or turn the wheel more and more slowly until the centrifuge is brought to a gentle stop.

(iii) Matched pairs of test tube holders of various sizes may be constructed and used interchangeably in the same centrifuge head, if desired.

(iv) When the wheel of this centrifuge is turned rapidly, about 150 turns per minute, for example, the centrifuge head spins at nearly 500 revolutions per minute.

VII. GAS GENERATORS

The apparatus used in the production of gases has been placed in two sections, one of which contains the complete apparatus for gas generation while the second section contains two devices useful in collecting gases.

A. GAS GENERATORS

Three types of generators will be given: simple devices for which no special equipment is required; and an inexpensive version of Kipp's gas generator.

B. ACCESSORIES

Included here are the beehive shelf and metal sheet shelf.

A. GAS GENERATORS

A1. Simple Gas Generator and Collecting Apparatus

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Generator Tube	1	Test Tube or Flask (A)	Capacity at least 50 ml
	1	1-Hole Rubber Stopper (B)	To fit generator tube (A)
(2) Delivery Tube	1	Glass Tubing (C)	0.5 cm diameter, 5-10 cm long
	1	Rubber or Plastic Tubing (D)	To fit glass tubing (C and E), 30 cm long
	1	Glass Tubing (E)	0.5 cm diameter, 15-25 cm long
(3) Collecting Apparatus	1	Test Tube, Flask, or Bottle (F)	Capacity at least 50 ml
	1	Bowl or Pan (G)	250 ml or greater capacity

b. Construction

(1) Generator Tube

For the generator tube, use a hard-glass test tube or flask suitable for heating (A). Secure test tube in a slanted position with an appropriate clamp or support (IV/B5 or B6).

Fit the generator tube with a one-hole rubber stopper (B).

(2) Delivery Tube

Insert the shorter glass tube (C) through the one-hole rubber stopper. Connect the rubber or plastic tubing (D) to the free end of the glass tube (C). Bend the longer glass tube (E) at a 90° angle or less, and connect it to the flexible tubing (D).

(3) Collecting Apparatus

Select a large test tube, flask, or bottle (F). Fill with water, cover the opening, and invert in a bowl or pan of water (G) so that the water is held in the bottle (F). Uncover the opening and place the free end of glass tubing (E) into the mouth of the collecting tube.

c. Notes

(i) This apparatus is suitable for student use in generating small amounts of gases which are insoluble or only slightly soluble in water.

(ii) Small amounts of reactants are placed in the generator tube and carefully heated (if heating is required). The gas generated passes through the delivery tube, and is collected by displacing the water in the collecting tube.

A2. Flask Generator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Generator Flask	1	Flask or Bottle (A)	250 ml capacity or larger
	1	2-Hole Rubber Stopper (B)	To fit flask (A)
(2) Funnel	1	Long-necked Funnel (C)	Approximately 10 cm diameter (large end)
(3) Delivery Tube	2	Glass Tubing (D)	0.5 cm diameter, 15-25 cm long
	1	Plastic or Rubber Tubing (E)	To fit glass tubing, approximately 30 cm long

b. Construction

(1) Generator Flask

Support the flask or bottle (A), if necessary, in a suitable support. Fit the flask with a two-hole rubber stopper (B).

(2) Funnel

Select a funnel (C) with a sufficiently long neck to reach nearly to the bottom of the flask (A). Carefully push the funnel neck through one of the holes in the stopper (B).

(3) Delivery Tube

Make a 90° bend in each piece of glass tubing (D). Connect

these with flexible tubing (E). Insert one of the glass tubes into the second hole of the rubber stopper (B).

c. Notes

(i) This apparatus is used in conjunction with the collecting apparatus just as described in the previous section (VII/A1).

(ii) This device is generally chosen when the gas generating reaction involves a solid (such as zinc) and a liquid (such as dilute sulfuric or hydrochloric acid). The solid is placed in the bottom of the generator flask, then the rest of the apparatus is placed in position. When the collecting bottle is in place, the liquid reagent is added through the funnel. Thus, the reaction does not begin until the apparatus is sealed. Additional liquid can be added to the flask without dismantling the apparatus.

(iii) If a funnel made from a cut-down bottle is used (V/A3), it will be necessary to adapt the construction of this item slightly. Connect such a funnel to the flask (A) with a long piece of glass tubing running through the stopper (B) and a one-hole stopper fitted into the funnel.

A3. Kipp's Generator *

*Adapted from C. S. Rao (Editor), Science Teachers' Handbook, (Hyderabad, India: American Peace Corps, 1968), pp 174-175.

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Acid Container	1	Glass Jar (A)	Capacity approximately 500 ml
	1	Rubber Stopper (B)	Approximately 2.0 cm diameter (large end)
	--	Plasticine (Modeling Clay) or Pitch (C)	4 cm x 4 cm x 4 cm
(2) Reaction Flask	1	Glass Bottle (D)	Capacity approximately 500 ml
	1	1 or 2-Hole Rubber Stopper (E)	To fit bottle (D)
	1	Glass Tubing (F)	Approximately 0.7 cm diameter, 30 cm long
	1	Rubber Tubing (G)	1.0 cm diameter, 3 cm long
	1	1-Hole Rubber Stopper (H)	Approximately 2.0 cm diameter (large end)
(3) Gas Delivery Tube	1	Glass Tubing (I)	0.7 cm diameter, 5 cm long
	1	Rubber Tubing (J)	1.0 cm diameter, 30 cm long
	1	Pinch Clamp (K)	(IV/A4)
(4) Funnel	1	Glass Bottle (L)	Capacity approximately 1 liter
	1	1-Hole Rubber Stopper (M)	To fit bottle (L)

b. Construction

(1) Acid Container

Select a low, wide-mouth jar with a capacity of about 500 ml (A). Drill a hole in the side of the jar, just above the bottom, (I/E2). Enlarge the hole, by filing with a round file, to a diameter of 1.7 - 1.8 cm. Seal this hole with a solid rubber stopper (B).

(2) Reaction Flask

For the reaction flask, choose a narrow-necked bottle (D) that will just fit into the neck of the acid container (A). Drill a hole in the center of the bottom of the bottle (D), and enlarge the hole to a diameter of 0.8 - 0.9 cm. Drill a second hole in the side near the bottom. Enlarge this hole to a diameter of 1.7 - 1.8 cm. Fit a one-hole rubber stopper (H) into the side hole.

Select a stopper (E) that fits the neck of the bottle (D). If it is a one-hole stopper with a round file, enlarge the hole in the stopper to about two to three times its normal diameter. Fit this stopper into the neck of the bottle. If a two-hole stopper is available, make no alterations, and fit the stopper into the neck of the bottle (D).

Fire polish (I/D4) both ends of the glass tubing (F). Insert one end into the short length of rubber tubing (G). Allow 4 - 5 cm of glass tubing (F) to protrude beyond the rubber tubing (G).

Insert the long end of the glass tubing (F) into the bottle (D), from the bottom. Fit the end through the enlarged hole of the stopper (E), and carefully push and twist until the rubber tubing (G) around the glass tightly seals the hole in the bottom of the bottle (D).

Set the reaction flask (D), neck down, into the neck of the acid container (A). Adjust and cut the glass tubing (F), if necessary, so its lower end is about 0.5 cm from the bottom of the acid container (A).

Roll the modeling clay (plasticine) (C) into a long cylinder and wrap it around the seam between reaction flask (D) and acid container (A). Press the clay firmly in place to make an airtight seal.

(3) Gas Delivery Tube

Insert a short piece of glass tubing (I) into the stopper in the side of the reaction flask. Attach rubber tubing (J) to the other end of the glass tube. Use a wooden pinch clamp (K) (IV/A4) or other suitable clamp to close the rubber tubing.

(4) Funnel

Construct a large funnel with a capacity equal to that of the acid container by cutting off the bottom third of a narrow-necked bottle (L) (I/F2). Smooth the rough cut edge of the funnel with emery cloth. Select a one-hole rubber stopper (M) to fit the funnel neck. Insert the glass tube (F) from the reaction flask (D) into the stopper (M).

Invert the funnel (L) and fit its neck tightly over the stopper (M).

Support the funnel in a ring stand (IV/B5) or other suitable holder.

c. Notes

(i) To complete the gas generating apparatus, the gas delivery tube of the Kipp's Generator must be connected to a suitable collection device such as that described in VII/A1, or the aspirator described in V/A8.

(ii) The solid reactant, such as zinc chips, is added to the reaction flask (D) through the hole in the side. The solid will sit, for the most part, on the stopper (E) in the neck of the flask. The stopper (H) and gas delivery tube are then securely replaced in the reaction flask, and all connections and seals are checked to insure that they are gastight. Then the liquid reagent, such as 6M hydrochloric acid, is poured into the funnel (L).

When the pinch clamp (K) is removed from the gas delivery tube, the acid will flow into the acid container (A). As the acid level rises above the neck

of the reaction flask (K), it will flow into the reaction flask through the enlarged or second hole of the stopper (E) and will react with the solid to produce a gas (hydrogen, in this example). The gas will pass through the delivery tube to the collecting vessel.

(iii) The reaction can be stopped without removing any of the reactants or dismantling the equipment. When the gas delivery tube is closed with the pinch clamp, the pressure of the gas accumulating in the reaction flask will force the acid out of the reaction flask and back into the acid container until it is no longer in contact with the solid. Some of the acid will also be forced back up the glass tube and into the funnel. The funnel must therefore be large enough to safely contain a large volume of acid that might be backed up.

To restart the reaction, the delivery tube is opened, and acid again flows into the acid container and reaction flask to evolve more gas.

(iv) This device is suitable for evolving large quantities of a gas for class use, or as a demonstration. It should be possible to build a larger model, but experimentation with the size relationships between the funnel, reaction flask, and acid container will be necessary.

(v) If the Kipp's Generator is to be employed for continuous classroom use, a safety tube and funnel may be substituted for the large funnel to prevent the escape of unpleasant or undesirable acid fumes. A piece of glass tubing, approximately 0.7 cm diameter and 35 - 40 cm long, is bent as shown. This is connected, by means of a rubber stopper at the upper end, to a funnel. A bottle with a hole drilled in the bottom is substituted for the large funnel (L), and the lower end of the safety tube is connected to this bottle with a one-hole rubber stopper or short piece of rubber tubing.

The whole apparatus must be supported in a stand or frame of some kind.

B. ACCESSORIES

B1. Beehive Shelf

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Tin Can (A)	9 cm diameter x 5 cm high

b. Construction

(1) Tin Can Shelf

Select a short tin can with one end removed (A). Cut a V-shaped notch about 1 cm high in the side of the can. Drill a hole 1.5 cm in diameter in the center of the end of the can. Varnish the can.

c. Notes

(i) The beehive shelf is placed in the bottom of a pan of water. A gas collecting tube or jar, filled with water as described in VII/A1, is inverted on the shelf, with the mouth of the jar over the hole in the shelf. The gas delivery tube is then inserted through the notch of the shelf, up through the hole, and into the neck of the collecting jar.

B2. Metal Sheet Shelf

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Shelf	1	Metal Sheet (A)	Approximately 0.05 cm thick, 8 cm x 30 cm

b. Construction

(1) Metal Sheet Shelf

Cut the metal sheet from heavy aluminum sheeting or a tin can. Cut three holes, 1.5 cm in diameter, in the sheet (A) as shown. Bend the edges up as shown. Finally, make curved bends approximately 1 cm from each end.

c. Notes

(i) This shelf may be hung from the sides of a rectangular pan measuring from 12 to 20 cm wide. The shelf must be covered with water. Collecting bottles, filled with water, are inverted over the holes and set on the shelf.

VIII. METALWARE AND CLEANER

A. METALWARE

The items in this section are small pieces of metalware which can be constructed from scrap strapping, wire and the like. Items which can be improvised from normal household items, such as knives, have not been included.

B. CLEANER

This item can be used to clean the test tubes utilized in chemistry.

A. METALWARE

A1. Flame Test Wire

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Wire	1	Transfer Loop	BIOL/VII/A3

b. Construction

(1) Wire — See BIOL/VII/A3 for construction details.

c. Notes

(i) Use this wire to flame test compounds. Simply get a small amount of the chemical caught in the wire loop and hold it in a hot flame to observe the color of the flame.

A2. Deflagrating "Spoon"

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Spoon	1	Metal Strapping (A)	About 10 cm x 3 cm

b. Construction

(1) Spoon

Bend Slightly

Sand Both Sides

Carefully sand off all the paint from one end of the metal strapping (A) so that there is only bare metal. Make a slight bend in this end about 1.0 cm from the end.

c. Notes

(i) To use the deflagrating spoon, place a small amount of the chemical to be heated on the bent portion of the strapping. Hold the spoon in a holder (e.g., IV/A4), and hold the chemical in the flame of a burner until it burns or melts. The deflagrating spoon is used mainly in doing flame tests on unknown compounds.

(ii) When the end of the spoon becomes contaminated, either clean it with sandpaper or simply cut it off, sand the new end, and bend it as before.

A3. Spatula

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Spatula	1	Tin Can or Strapping Wire (A)	20.0 cm long, 3.0 cm wide

b. Construction

(1) Spatula

Cut a piece of tin can metal (A) or a piece of wire strapping to the desired length and width. Cut the metal to the shape illustrated.

Make a depression in the scoop by hammering a steel ball in the circle.

Depress the center of the handle slightly for easier handling.

c. Notes

(i) This spatula may be converted to a deflagrating spoon by bending the handle backward at a 90° angle with the shaft and bending the scoop forward at a 90° angle with the shaft.

B. CLEANER

B1. Test Tube Cleaner or Spatula

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Handle	1	Wooden Dowel (A)	25 cm long
(2) Cleaner	1	Piece of Rubber Inner Tube (B)	5 cm x 5 cm

b. Construction

(1) Handle

Use a piece of wooden dowel (A) about 25 cm in length. Make a slit about 2.0 cm long in the center of one end of the handle.

(2) Cleaner

Cut a triangular piece of rubber (B) about 5.0 cm long from a discarded inner tube. Insert this in the slit made in the handle. Drive a small nail through the handle and cleaner to hold them in place, if necessary.

IX. HEATERS AND DRYERS

The apparatus in this section has been divided into two categories, as follows:

A. DRYERS

Dryers are devices used to remove the moisture content from chemical compounds.

B. HEATER

This is a device that is intended to produce a heat intense enough to incinerate precipitates.

A. DRYERS

A1. Dessicator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Glass Jar (A)	Capacity 200 ml or more
	1	Lid (B)	To fit jar (A)
(2) Dryer	1	Small Tin Can (C)	To fit inside jar (A)
	1	Wire Mesh (D)	To cover tin can (C)
	--	Calcium Chloride or Silica Gel (E)	--
(3) Tubing	1	Rubber Tubing (F)	1 cm diameter, 15 cm long
	1	Glass Tube (G)	0.7 cm diameter, 5 cm long
	1	Screw Clamp or Pinch Clamp (H)	(IV/A4 or A5)

b. Construction

(1) Container

Select a jar (A) with a screw top (B) and a very wide mouth. Cut a hole slightly less than 1.0 cm in diameter in the center of the jar lid (B).

(2) Dryer

Take a short tin can (C) which fits easily into the jar, or cut a taller can to a height of 2 - 3 cm.

Place a drying agent, such as calcium chloride ($CaCl_2$) pellets or silica gel (C) in the can. Cover the can with wire mesh (D) and set it in the bottom of the jar (A).

Cut a section of about 3 cm from the piece of rubber tubing (F). Insert one end of the glass tube (G) all the way into this short piece of rubber tubing. Insert the other end of the glass tube (G) into the longer section of rubber tubing. Push the shorter piece of rubber tubing, with the glass tube inside, into the hole in the top of the jar lid (B). Seal the tubing into the hole in the jar with cement, if necessary, to make an airtight seam. Seal the long rubber tube with a pinch clamp (IV/A4) or screw clamp (IV/A5).

c. Notes

(i) Powders or substances to be kept free of moisture are placed in containers inside the dessicator, and the top is sealed. The rubber and glass tube arrangement permits a partial vacuum to be formed in the dessicator if it is used in conjunction with a vacuum pump.

A2. Drying Tower

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Glass Bottle (A)	Capacity approximately 300-400 ml
	1	1-Hole Stopper (B)	To fit bottle (A)
(2) Tubing	3	Rubber Tubing (C)	1 cm diameter, 5 cm long
	2	Glass Tubing (D)	0.7 cm diameter, 5 cm long

b. Construction

(1) Container

Drill a hole just slightly smaller than 1.0 cm in the side of the bottle (A) near the bottom (I/E2). Fit the bottle (A) with a one-hole cork or rubber stopper (B).

(2) Tubing

Insert one of the pieces of glass tubing (D) into the one-hole stopper, and push a piece of rubber tubing (C) on to the other end of the glass tube.

Insert one piece of rubber tubing (C) into the hole in the bottle (A), and cement it in place to make an airtight seal. Push the second piece of glass tubing (D) into the rubber tubing (C), and connect the last piece of rubber tubing (C) to the glass tube (D).

c. Notes

(1) This apparatus is used in removing moisture from gases. For example, moisture can be eliminated from H_2, O_2, N_2, Cl_2, and SO_2 by filling the drying tower with calcium chloride or other drying agent and connecting it by means of the tubing connections at top and bottom, between the gas generator and collecting device. As the gas passes through the drying tower, moisture is absorbed by the drying agent.

A3. Electric Lamp Dryer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	30 cm x 30 cm x 1 cm
	1	Wood (B)	1 cm x 2 cm x 32 cm
	1	Wood (C)	1 cm x 2 cm x 18 cm
	2	Wood (D)	4 cm x 4 cm x 2 cm
(2) Lamp	1	Lamp Socket (E)	--
	1	Insulated Electrical Cord and Plug (F)	--
	1	Incandescent Bulb (G)	100 watts
	4	Large Staples or Thin Nails (H)	--
	1	Bolt (I)	Approximately 0.8 cm x 3 cm
	1	Nut (J)	To fit bolt (I)
	1	Wire Mesh (K)	20 cm x 20 cm
	1	Thin Wire (L)	15 cm
	1	Aluminum Foil (M)	20 cm x 20 cm

b. Construction

(1) Support

Construct the support as illustrated. Use glue and screws to secure the parts (A), (B), (C), and (D) to one another.

(2) Lamp

Secure the lamp socket (E) to the top horizontal bar (C) with the nut (J) and bolt (I).

Attach the electrical cord, with plug attached (F), to the socket (E). Run the wire along the top bar (C) and down the back of the vertical support (B). Secure the cord in position with large staples (H), bent nails, or tape.

From the wire mesh (K), cut a circle. Cut out and remove the shaded portion as shown. Cut a similar but slightly larger shape from the aluminum foil (M). Curve the wire mesh (K) into a cone with an open end that will fit over the base of the incandescent bulb (G), and secure the cut edges together by threading the thin wire (L) in and out of the wire mesh.

Cover the inside of the wire mesh cone (K) with the foil (M), shiny side to the inside of the cone. Secure the foil reflector (M) to the wire mesh (L) by bending the foil edges around the wire mesh cone.

Slip the small end of the reflector over the neck of the bulb (E) and screw the bulb into the socket (E).

c. Notes

(i) The light provides a heat source for drying precipitates which are placed in shallow containers, watch glasses (V/A5) or petri dishes (V/A6).

(ii) Experimentation in the use of the dryer might include varying the size of the reflector, distance of the bulb from the material, wattage of bulb and number of bulbs used.

A4. Sand Bath

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Can	1	Large Tin Can (A)	15-20 cm diameter
	--	Sand (B)	--

b. Construction

(1) Can

Use a large, shallow tin can (A) as a container, or cut a larger can to a height of about 5 cm. Fill the container with sand (B).

c. Notes

(1) Solutions or precipitates that must be evaporated or dried slowly may be placed in shallow containers, watch glasses, or petri dishes which are rested on the sand. The sand bath is then rested on a tripod (IV/B3), heating stand (IV/B4) or other suitable support and slowly heated with an alcohol or gas burner.

A5. Water or Steam Bath

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Tin Can (A)	Capacity approximately 150-300 ml

b. Construction

(1) Container

Use an empty, clean tin can (A) for the container. Fill it about 2/3 full of water.

c. Notes

(i) Use of the water bath is a safe way to heat materials that must not, for technical or safety reasons, be heated above about 100°C. Test tubes containing material to be heated are placed in the water bath. The water bath is rested on a suitable support and heated with an alcohol or gas burner. Materials heated in the test tubes will be heated to a temperature not higher than the boiling point of the water.

(ii) The water bath may be converted to a steam bath by the addition of a row of holes punched or drilled around the can near the top. The can is filled about 1/3 full of water, and a petri dish (V/A6) or watch glass (V/A5) containing material to be heated is rested on top.

The steam bath is rested on a suitable support and heated; as the water boils, the steam will heat the material in the petri dish or watch glass and will be able to escape through the holes in the top of the can.

B. HEATER

B1. Blowpipe for Charcoal Block

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Blowpipe	1	Rubber Tubing (A)	Approximately 1.0 cm diameter, 10 cm long
	1	Glass Tubing (B)	Approximately 0.7 cm diameter, 20 cm long
(2) Charcoal Block	1	Charcoal Block (C)	--

b. Construction

(1) Blowpipe

Heat the glass tubing (B) near one end and bend it slightly as shown. Then heat it again, just past the bend, in order to draw it out to form a nozzle.

Fit the rubber tubing (A) over the other end of the glass tube (B).

(2) Charcoal Block

Use a lump of charcoal (C) as a heat source.

c. Notes

(i) This item is used to create a concentrated heat source by blowing through the blowpipe onto the charcoal ember.

X. MOLECULAR MODELS

Four types of models to assist in the instruction and understanding of molecular structure are described.

A. SPACE-FILLING MODELS

These roughly represent relative sizes and positions of atoms within a molecule.

B. SKELETAL MODELS

These models more accurately represent atomic radii and bond angles than do those in the previous section.

C. CRYSTAL MODELS

These are three-dimensional models that represent shape and atomic packing within crystals.

D. KINETIC-MOLECULAR MODEL

This two-dimensional model demonstrates the kinetic theory of matter.

A. SPACE-FILLING MODELS

A1. Ball-and-Stick Models

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Ball	1	Block of Styrofoam Plastic or Foam Polystyrene (A)	Approximately 4 cm x 10 cm x 10 cm
	1	Electric Bottle Cutter (B)	(I/F2)
	1	Thin Nichrome Wire (C)	0.02 cm diameter, 35 cm long

(2) Rigid Connector	1	Box of Toothpicks (D)	Approximately 250
(3) Flexible Connector	1	Package of Pipe Cleaners (E)	Approximately 25

b. Construction

(1) Ball

Construct the electric bottle cutter (B) according to directions given in (I/F2). Substitute the thin nichrome wire (0.02 cm diameter) for that described and stretch it tightly between the terminals. Connect the terminals to a six volt battery or a transformer that steps line current down to about six volts.

Form the styrofoam (A) into small balls. First, cut the block into cubes, determining the sizes according to the element each represents:

H - 1.5 cm on a side
C - 3 cm " " "
O - 3 cm " " "
Si - 4 cm " " "

To cut a precise straight line, brace a large wooden block against the base of the bottle cutter, with one edge as far from the taut wire as the width of the desired cut. Push the styrofoam block (A) down on the hot, taut wire to slice it, holding it against the wooden block which acts as a guide.

Carefully cut the corners off each cube to approach the shape of a sphere.

Last, shape the trimmed cubes with the fingers more exactly into spheres.

For clarity in the finished models, paint the balls with tempera (poster paint) to which a small amount of dissolved soap has been added. Use the following colors to represent:

H - white
C - black
O - red

(2) Rigid Connectors

Stick toothpicks (D) into the styrofoam balls to represent sigma bonds between atoms, as in the ethane molecule (C_2H_6) represented here.

(3) Flexible Connectors

Use pairs of pipe cleaners (E) cut to approximately 5 cm lengths to represent pi bonds between atoms, as in the ethene (ethylene; C_2H_4) molecule represented here.

When triple bonds (one sigma and two pi bonds) are to be represented, dye the two pairs of pipe cleaners different colors for clarity. This diagram represents a molecule of ethyne (acetylene; C_2H_2).

c. Notes

(i) If commercially manufactured styrofoam or foam polystyrene balls are easily available, they may be substituted for the hand-made balls described here.

(ii) The scale of approximate sizes of the balls used in these models is based on the atomic radii for stable compounds listed in the Periodic Table of the elements, for example:

Element	Atomic Radius in Angstroms	Approximate Ratio
C	0.77	2
N	0.75	2
O	0.73	2
H	0.32	1

(iii) If styrofoam or foam polystyrene is not available, modeling clay (plasticine) may be used for the balls and painted appropriate colors. However, once the clay balls are painted, repeated puncturing of them with toothpicks will disfigure them. Thus, it is recommended that they be used only to make permanent demonstration models.

(iv) Pipe cleaners or match sticks may be substituted for the toothpicks if desired.

(v) A kit for teacher use should contain:

2 dozen balls representing Carbon
2 dozen " " Hydrogen
2 dozen " " Oxygen
1 dozen " " Halogens
1 dozen " " Nitrogen
1 dozen " " Sulfur
several dozen each straight and flexible connectors.

This would provide sufficient materials for constructing demonstration models in the classroom. The same quantities listed above would be adequate for laboratory use for from one to four students.

(vi) The use of molecular models in the study of chemistry can enhance the students' understanding of and ability to predict the various properties and interactions of elements and compounds. These ball and stick models illustrate, roughly, the relative bond angles, sizes and positions of atoms within a molecule in a clear and simple form. They are not, however, scale representations of bond lengths or atomic molecular sizes and shapes. In order to demonstrate the mathematical relations of electrons in a given molecule, it will be necessary to employ a different style model, that which is described in the next section.

(vii) The color code * used in these models is as follows:

Hydrogen - white
Carbon - black
Oxygen - red
Nitrogen - blue
Sulfur - dark yellow
Flourine - light green
Chlorine - dark green
Bromine - orange
Iodine - brown
Phosphorous - violet
Silicon - light yellow

*From the Portland Project Committee, Teacher Guide, Chemistry of Living Matter, Portland, Oregon: Portland Project Committee, (1971, p 17.

B. SKELETAL MODELS

B1. Molecular Model Units*

Assembled View

Exploded View

*Adapted from George C. Brumlik, Edward J. Barrett, and Reuben L. Baumgarten, "Framework Molecular Models," Journal of Chemical Education, XLI (1964), pp 221-223.

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Tubing	--	Milk Straws (Paper or Plastic) (A)	0.4 cm diameter, approximately 20 cm long
	--	Tempera (Poster) Paints (B)	Black, white, red, yellow, green, blue, orange
(2)	--	Pipe Cleaners (C)	--
(3) Connector	--	Pipe Cleaners (D)	--
	--	Finishing Nails (E)	Approximately 0.1 cm diameter, 1.5 cm long
	--	Soft Iron Wire (F)	Approximately 0.05 cm diameter

b. Construction

(1) Tubing

Mix a small amount of liquid or dissolved soap with the tempera paints (B) to reduce their surface tension. Using this mixture, paint several milk straws (A) according to the atom they are to represent:

Carbon - black
Hydrogen - white
Oxygen - red
Nitrogen - blue
Sulfur - dark yellow
Bromine - orange
[Consult Note (ii) for additional colors.]

Cut the straws into various lengths depending upon the scale used and bond represented.

(2) Valence Cluster

Bend a pipe cleaner (C) into the shape desired, and glue the joint in the middle. When the glue has dried, adjust the angles of the arms of the connector to suitable angles.

Bend

Make tetrahedral (4 arms) shapes with the angles of the arms at about 109°.

Make trigonal bipyramid (5 arms) shapes. Arrange the angles between the three horizontal arms to 120°. Adjust the two vertical arms at right angles to the horizontal arms.

Construct octahedrons (8-pointed). Adjust the angles between the four horizontal arms to 90°. Arrange the two vertical arms at right angles to the horizontal arms.

(3) Connectors

Construct straight connectors to represent bonds between atoms by wrapping a pipe cleaner (C) around a nail (E). Vary the length of pipe cleaner used according to the tightness desired.

To make angular connectors to be used to complete various structures, bend a pipe cleaner (C) in half. Then wrap soft wire (F) around the pipe cleaner and bend the assembly to a 90° angle.

c. Notes

(i) These units can be used to build models of almost any molecule. The valence clusters represent atomic nucleii, the intersection of the arms representing the center of the atom. The tetrahedral (4-armed) valence cluster depicts bond angles

of approximately 109°, for sp^3 hybridized orbitals or atoms with eight electrons in their valence shell. The five-armed valence cluster can depict sp^2 hybridization, with 120° bond angles, for atoms engaged in π (pi) bonds, as well as d sp^3 hybridization, with 90° and 120° bond angles for atoms with ten atoms in their valence shell. The six-armed valence cluster can represent sp hybridization with bond angles near 180°, or d^2sp^3 hybridization for atoms with twelve electrons in their valence shell. The straight connector depicts σ (sigma) bonds between like or unlike atoms.

Electrons, whether bonded or unshared, are represented by the straws, color coded and cut to scale.

The straws in a completed molecular model represent covalent radii of bonding atoms, and van der Waals radii in the non-bond direction.

(ii) Below are charts* to guide the coloring and cutting of straws to represent covalent radii or van der Waals radii. Any convenient scale may be used to simulate the Ångstrom unit (Å) measurements of these forces. For example, a scale of 10 cm/Å produces large models ideal for lecture demonstrations, while a scale of 2 cm/Å yields smaller models suitable for student use.

Bond	Atomic Covalent Radii (Å)	Length of Straw in cm (Scale: 10 cm/Å)	Length of Straw in cm (Scale: 2 cm/Å)	Color of Straw
C - single	0.77	7.7	1.5	
C - double	0.67	6.7	1.3	black
C - triple	0.60	6.0	1.2	
O - single	0.74	7.4	1.5	
O - double	0.62	6.2	1.2	red
O - triple	0.55	5.5	1.1	
N - single	0.74	7.4	1.5	
N - double	0.62	6.2	1.2	blue
N - triple	0.55	5.5	1.1	

*Adapted from the Portland Project Committee, Teacher Guide, Chemistry of Living Matter, (Portland, Oregon: Portland Project Committee, 1971), pp 8-18.

Bond (single)	Atomic Covalent Radii (Å)	Length of Straw in cm (Scale: 10 cm/Å)	Length of Straw in cm (Scale: 2 cm/Å)	Color of Straw
H	0.30	3.0	0.6	white
F	0.64	6.4	1.3	light green
Si	1.17	11.7	2.3	light yellow
P	1.10	11.0	2.2	violet
S	1.04	10.4	2.1	dark yellow
Cl	1.00	10.0	2.0	dark green
Br	1.14	11.4	2.3	orange
I	1.33	13.3	2.7	brown

Atom	Van der Waals Radii (Å)	Length of Straw in cm (Scale: 10 cm/Å)	Length of Straw in cm (Scale: 2 cm/Å)	Color of Straw
H	1.2	12.0	2.4	white
O	1.40	14.0	2.8	red
F	1.35	13.5	2.7	light green
S	1.85	18.5	3.7	dark yellow
Cl	1.80	18.0	3.6	dark green
Br	1.95	19.5	3.9	orange
I	2.15	21.5	4.3	brown
N	1.5	15.0	3.0	blue
P	1.9	19.0	3.8	violet

B2. Single Bond Structures*

*Adapted from the Portland Project Committee, Teacher Guide, Chemistry of Living Matter, (Portland, Oregon: Portland Project Committee, 1971), pp 19-28.

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Carbon-Carbon	1	Straight Connector (A)	X/B1
	2	Black Straws (B)	1.5 cm
(2) Carbon-Oxygen	1	Straight Connector (C)	X/B1
	1	Black Straw (D)	1.5 cm
	1	Red Straw (E)	1.5 cm
(3) Carbon-Hydrogen	1	Straight Connector (F)	X/B1
	1	Black Straw (G)	1.5 cm
	1	White Straw (H)	3.0 cm
(4) CH_4 (Methane)	1	4-armed Valence Cluster (I)	X/B1
	4	Carbon-Hydrogen Bonds (F,G,H) [see (3) above]	4.5 cm
(5) H_2O (Water)	1	4-armed Valence Cluster (J)	X/B1
	2	Red Straws (K)	1.5 cm
	2	Red Straws (L)	2.8 cm
	2	White Straws (M)	3.0 cm
	2	Straight Connectors (N)	X/B1

b. Construction

(1) Carbon-Carbon

To represent this single covalent bond between like atoms, cut two black straws (B) to a scale representation of the single bond covalent radius of carbon (X/B1), Note (ii). For example, cut the straws to 1.5 cm for a scale of 2 cm/Å. Join these two straws with a straight connector (A).

(2) Carbon-Oxygen

To construct this model of a single covalent bond between unlike atoms, cut one black straw (D) to represent the single bond covalent radius for carbon (1.5 cm, for example) and a red straw to represent the single bond covalent radius for oxygen (E) (1.5 cm). Connect

these two straws with a straight connector (C).

(3) Carbon-Hydrogen

Construct the carbon-hydrogen bond to include a representation of the van der Waals radius for hydrogen. Cut one black straw (G) to indicate the single bond covalent radius for carbon. Cut one white straw (H) to show the covalent radius of H (0.6 cm) plus the van der Waals radius of H (2.4 cm). Draw a line around the white straw at the intersection of these two values to indicate the position of the hydrogen nuculeus, then join the black and white straws with a straight connector (F).

(4) CH_4 (Methane)

Construct four carbon-hydrogen bonds (F,G,H) as described above. Join them all together at the carbon end by sliding each onto an arm of the four-armed valence cluster (I) and pushing all the straws together so that the connectors do not show.

(5) H_2O (Water)

Cut two red straws (L) to represent the van der Waals radius of O (2.8 cm). These will represent two unshared electron pairs. Cut two red straws (K) to indicate the single bond covalent radius of O (1.5 cm). Use a straight connector (N) to join each of these with a white straw (M) representing the covalent and

van der Waals radii of H (3.0 cm). Connect the two red straws and two O - H bonds with a four-armed connector (J) as illustrated.

c. Notes

(i) Single covalent bonds between like atoms, such as the carbon-carbon bond, may also be represented by one straw, appropriately colored, cut to twice the covalent radius. Thus, the carbon-carbon bond would be represented by one black straw, 3 cm long.

C C

(ii) Unlike the space-filling models of X/A1, these models do not show molecular shape. The shape of the constituent atoms within a molecule must be imagined; the scale and orientation of the parts of the model show bond lengths, bond angles, and bond thicknesses in reasonably accurate scale.

(iii) These skeletal molecular models are based on atomic orbital geometry, which deals with the behavior of electrons in paths, or orbitals, in the space around the nucleus of an atom. For a complete discussion of electrons, nucleii, and orbitals, consult recent chemistry texts, such as Chemical Bond Approach Project, Chemical Systems, (Webster Division McGraw-Hill Book Company, 1964), Chapter 10.

B3. Double Bond Structures*

*Adapted from the Portland Project Committee, Teacher Guide, Chemistry of Living Matter, (Portland, Oregon: Portland Project Committee, 1971) pp 28-36.

(3) C_6H_6
(Benzene)

(4) $H_2C = C = CH_2$
(Allene)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) $H_2C{=}CH_2$ (Ethene)	2	5-armed Valence Clusters (A)	X/B1
	4	C-H Bonds (B)	4.5 cm
	3	Black Straws (C)	2.6 cm
	4	Black Straws (D)	3.0 cm
	4	Angular Connectors (E)	X/B1
(2) $H_2C{=}O$ (Formaldehyde)	2	5-armed Valence Clusters (F)	X/B1
	4	Angular Connectors (G)	X/B1
	2	C-H Bonds (H)	4.5 cm
	3	Red Straws (I)	1.2 cm
	3	Black Straws (J)	1.3 cm
	2	Red Straws (K)	3.0 cm
	2	Black Straws (L)	3.0 cm
	2	Red Straws (M)	1.5 cm
	3	Straight Connectors (N)	X/B1
(3) C_6H_6 (Benzene)	18	5-armed Valence Clusters (O)	X/B1
	6	C-H Bonds (P)	4.5 cm
	18	Black Straws (Q)	2.6 cm
	12	Black Straws (R)	3.0 cm
(4) $H_2C{=}C{=}CH_2$ (Allene)	2	5-armed Valence Clusters (S)	X/B1
	1	6-armed Valence Clusters (T)	X/B1
	4	C-H Bonds (U)	4.5 cm
	6	Black Straws (V)	2.6 cm
	8	Black Straws (W)	3.0 cm
	8	Angular Connectors (X)	X/B1

b. Construction

(1) $H_2C{=}CH_2$ (Ethene)

First construct four C-H bonds (B) (X/B2). Then complete the $H_2C{=}CH_2$ molecule as shown. Use three 2.6 cm black straws (C) to represent double bond formation between like atoms. The central black straw (C)

represents the σ bond. The two outside sections of black straws (C) represent the two arms of the π bond, the thickness of which is shown by the four 3.0 cm black straws (D). Their length represents the single bond covalent radius of carbon.

(2) $H_2C=O$ (Formaldehyde)

Construct this model showing double bond formation between like atoms. First, construct three C=O bonds representing the double bond radii C (J) and O (I), as shown. Make two C-H bonds (H) (X/B2).

Use the 5 armed valence clusters (F) and angular connectors (G) to join the straws. Indicate the thickness of the π bond by red straws on the oxygen side, black straws on the carbon side.

(3) C_6H_6 (Benzene)

Cut off and discard one horizontal and one vertical arm from each of twelve 5-armed valence clusters (O) to form 3-cornered clusters.

One corner, exploded view

Make six C-H bonds (X/B2) (P). Construct the three layered model as shown. Use the twelve 3.0 cm black straws (R) to represent the thickness of the π bonds (twice the single covalent radius of carbon). Use the eighteen 2.6 cm black straws (Q) to represent the bond lengths (twice the double covalent bond radius of carbon). The shared-bond aspect of the ring structure often pictured:

is represented in the model by the three-layered structure.

(4) $H_2C{=}CH_2$ (Allene)

Construct four C-H bonds (U). Use one 6-armed valence cluster (T), as well as two 5-armed clusters (S), to connect the the components of the H_2C-C-CH_a (allene) molecule.

Place the 6-armed cluster (T) as shown to indicate that the middle carbon atom is π bonded to each of the side carbons.

c. Notes

(i) These four examples of double bond models illustrate some of the complex double bond forms that can be built. By applying the principles thus illustrated, it should be possible to construct almost any simple or complex double bonded molecule.

(ii) Because the forces holding two nucleii together in a double bond are greater than those in a single bond, the nucleii are closer together. Thus, the straws representing the C=C or C=R covalent distance are shorter than those representing the C-C or C-R distance.

(iii) In the H_2O=O (formaldehyde) molecule, the slightly longer tubing representing the π bond thickness at the carbon atom than at the oxygen atom indicates a certain strain on the double bond. The covalent radius of oxygen is used to model the unbonded electrons, rather than the van der Waals radius as in the model of water, because the C=O bond "pulls" or distorts the oxygen electron cloud. C=N bonds may be constructed just as C=C and C=O bonds; blue tubing represents N.

B4. Triple Bond Structure*

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) HC=CH (Acetylene)	2	6-armed Valence Clusters (A)	X/B1
	8	Angular Connectors (B)	X/B1
	2	C-H Bonds (C)	4.5 cm
	5	Black Straws (D)	2.4 cm
	8	Black Straws (E)	3.0 cm

*Adapted from the Portland Project Committee, Teacher Guide, Chemistry of Living Matter,(Portland, Oregon: Portland Project Committee, 1971), pp 36-37.

b. Construction

(1) HC=CH (Acetylene)

First make two C-H bonds (C) (X/B2). Then use two 6-armed valence clusters (A) and eight angular connectors (B) to connect the parts of the HC=CH (acetylene) molecule as shown. The 2.4 cm black straws (D) indicate the length of the triple bond, and are cut to represent twice the triple covalent bond radius for carbon. Bond thickness is indicated by the 3.0 cm straws (E) or twice the single bond radius for carbon.

c. Notes

(i) Because the forces holding two nucleii together in a triple bond are stronger even than those of a double bond, the nucleii are closer together. Thus, the straws representing the C=R covalent distance are shorter than those representing the C=R distances. Nucleii involved in sp hybridization with triple bond formation are represented in the model by the 6-armed sp valence cluster.

(ii) In the HC=CH (acetylene) model, the central carbon-carbon bond represents the σ bond. The four outside sections of black straws represent two double-armed π bonds.

B5. Geometric Structures*

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Straws	--	Paper or Plastic Milk Straws (A)	Approximately 0.4 cm diameter
	--	Pipe Cleaners (B)	Approximately 3 cm long

b. Construction

(1) Straws

Cut the straws (A) to any convenient length, 5 cm, for example. Paint the straws, if desired, with poster (tempera) paints to which a small amount of dissolved soap has been added.

*Adapted from D.C. Hobson and C. V. Platts, "Milk-Straw Molecular Models," School Science Review, CLXIII (1966), pp 694-701.

(2) Connectors

Bend the cut pipe cleaners (B) to form right angles.

Insert the pipe cleaners (B) into the straws (A), as shown, to form secure connections.

c. Notes

(i) By selecting appropriate numbers of straws and connectors, a variety of geometric forms may be built.

C. CRYSTAL STRUCTURE MODELS

Cl. Crystalline Packing Models*

*Adapted from J. W. Coakham, W. Evans, and H. Nugent, "Introducing Crystal Structures," School Science Review, CLXXIV (1969), pp 61-71.

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body-Centered Cubic Unit Cell	9	Styrofoam or Foam Polystyrene Spheres (A)	Approximately 4 cm diameter
(2) Face-Centered Cubic Unit Cell	14	Styrofoam or Foam Polystyrene Spheres (B)	Approximately 4 cm diameter
(3) Closely-Packed Hexagonal Unit Cell	17	Styrofoam or Foam Polystyrene Spheres (C)	Approximately 4 cm diameter

b. Construction

(1) Body-Centered Cubic Unit Cell

Make the spheres (A) from styrofoam or foam polystyrene (X/B1) or purchase spheres from a commercial source. Use the nine spheres to represent the atoms of the crystal according to the "exploded" diagram. Place four spheres in the top and bottom layers, and one in the middle. Use toothpicks, pipe cleaners, match sticks, or cement to hold the spheres together.

(2) Face-Centered Cubic Unit Cell

Use this exploded diagram as a guide for building the face-centered cubic unit cell from 14 spheres (B). Place five spheres in both top and bottom layers, and four spheres in the middle layer.

(3) Closely-Packed Hexagonal Unit Cell

Use seventeen spheres (C) as illustrated to build the closely-packed hexagonal unit cell. Place seven spheres in the top and bottom layers, with three in the middle layer.

c. Notes

(i) The models described demonstrate three-dimensional patterns found in crystals of metals, where the atoms are all of one size and the bonding forces are equal in all directions. As with previous models, the use of molecular models aids the student in both understanding the structure and predicting the characteristics of the substances studied.

(ii) If it is necessary to construct crystal models showing different ion sizes, smaller or larger styrofoam spheres may be used. For example, ionic crystal models may be constructed using spheres 2 cm in diameter for anions, and 0.2 cm diameter for cations.

(iii) These models may be also used to demonstrate such aspects of crystal structures as coordination number, most closely-packed planes and Miller Indeces.

(iv) For further discussions on the application of these models to the study of the molecular structure of crystals, consult J. W. Coakham, W. Evans, and H. Nugent, "Some Aspects of Crystal Structure, Part I," School Science Review, CLXXIX, pp 339-350.

D. KINETIC-MOLECULAR MODEL

D1. Kinetic Theory Model*

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Tray	1	Wood (A)	1 cm x 30 cm x 30 cm
	2	Wood (B)	2 cm x 2 cm x 26 cm
	2	Wood (C)	2 cm x 2 cm x 30 cm
(2) Dowel	1	Wooden Dowel (D)	Approximately 1.5 x 40 cm
(3) Marbles	250	Marbles or Glass Beads (E)	Approximately 1.0-1.5 cm diameter
	5	Marbles or Glass Beads (F)	Larger than the others

b. Construction

(1) Tray	Nail or glue the four wood strips (B and C) to the flat wood square (A) to form a tray. Varnish the tray inside and out to provide a slick inside and outside surface.
(2) Dowel	Select a dowel (D) to support one end of the tray.
(3) Marbles	Place the marbles or plastic or glass beads (E) in the tray. Use all of them to represent the molecules in a solid or liquid. Use only 40 - 50,

*Adapted from I. D. Taylor, "Kinetic Theory Models," School Science Review, CLXIII (1963), pp 780-783.

plus the few larger marbles (F), to represent the molecules in a gas.

c. Notes

(i) To demonstrate, two-dimensionally, the kinetic activity of molecules in matter, place all the marbles in the tray. Rest one end of the tray on the dowel so that the marbles all roll to the opposite end, packing into a regular structure with each marble, or "molecule" touching six neighbors.

(ii) When the tray is at rest, none of the "molecules" move, representing the theoretical condition of matter at absolute zero. When the tray is gently agitated back and forth, the "molecules" begin to vibrate and to show "thermal expansion". They occupy a larger volume, but generally retain the same relative position. Occasionally a few molecules jump clear of the surface, representing the slight vapor pressure of a solid.

(iii) As the tray is agitated still harder, with greater amplitude, the "solid" "melts" with the "increase in temperature" (increase in kinetic energy). The molecules slip out of place, the volume increases, and more molecules jump away from the surface.

By slowing down the rate and amplitude of vibration, the "liquid" can be converted back to a "solid". Slowing the vibration gently represents gradual cooling and results in a regular structure. If, however, the vibration suddenly ceases, rapid cooling is demonstrated. The resulting "solid" shows an irregular structure with many imperfections.

(iv) For a demonstration of a "gas", most of the molecules are removed, and the tray is agitated more rapidly than for the "solid" or "liquid". All the

molecules move rapidly and randomly about, traveling large distances before colliding with one another. A few larger marbles, added to the "gas", move with small, irregular, jerky motions, representing the Brownian motion of dust or smoke particles in air.

(v) If a clean glass tray and overhead projector is available, the model may be projected on a screen for a large class to see. The "molecules" show on the screen as shadows.

XI. CHROMATOGRAPHIC APPARATUS

Chromatography, a powerful analytical technique of recent development, may be performed with relatively simple apparatus. It is based upon the differential migra tion of solutes in a liquid or solid medium and maybe used for both qualitative and quantitative analysis of solutions.

A. QUALITATIVE CHROMATOGRAPHIC APPARATUS

This section includes chromatographic devices employing paper as the stationary medium and briefly describes a few techniques for using these devices to identify the components of a mixture.

B. QUANTITATIVE CHROMATOGRAPHIC EQUIPMENT

This section describes a device that allows for the separation of the components of a mixture as well as the recovery of individual components for further experimentation or purification.

A. QUALITATIVE CHROMATOGRAPHIC APPARATUS

A1. Horizontal Paper Chromatography Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Paper	1	Filter Paper (A)	Approximately 10 cm diameter or larger
(2) Support	1	Petri Dish (B)	Slightly smaller than filter paper

b. Construction

(1) Paper — Use a circle or square of filter paper (A) as the medium for the chromatogram.

(2) Support — Select a petri dish or other shallow container (B) just slightly smaller than the paper (A) on the support (B).

c. Notes

(i) This apparatus can be set up almost instantaneously for rapid, qualitative work. A drop of a colored solution to be analyzed is placed in the center of the paper. Then, successive, small drops of the eluting solvent are dropped on top of the original drop. The solution spreads radially, and as separation of components occurs, concentric rings of color will appear on the paper.

(ii) As an example of a test solution, a drop of black or blue-black, washable ink may be used. The eluting solvent in this case could be water, methanol (methylated spirits) or 70% ethanol.

(iii) Chromatography paper, white paper towels, blotting paper, newsprint paper, or other white or light-colored, coarse-grained paper may be substituted for the filter paper (A).

A2. Horizontal Paper Chromatography Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Paper	1	Filter Paper (A)	Approximately 10 cm diameter or larger
(2) Support	1	Cup or Jar (B)	Slightly smaller than filter paper
(3) Cover	1	Glass Jar or Bowl (C)	To cover paper and support

b. Construction

(1) Paper

Take a circle or square of filter paper (A) or suitable substitute and cut a tongue across the paper to within about 1 cm of the center of the

*Adapted from A. V. Jones, "Chromatography for Junior Schools," School Science Review, CLXXIX: (1970), 298-300.

paper. Bend the tongue down at a right angle to the paper (A).

(2) Support

Select a small cup or jar (B) just slightly smaller than the paper (A). Rest the paper (A) on the jar (B) with the paper tongue extended into the jar.

(3) Cover

Select a large glass jar or bowl (C) to cover the support and paper. Invert the cover to enclose the other two components.

c. Notes

(i) This apparatus, while only slightly more complex than that in the previous section, has the added advantage that, once set up, it may be left to stand for some time. A spot of test solution (e.g., ink or a concentrated extract made from plant flowers, leaves, stems, or roots) is placed at the center of the paper (A). Then the small jar (B) is filled to within about 2 cm of the top with solvent (e.g., water or alcohol). When the paper tongue is placed in the solvent, the liquid will soak up the tongue to the test spot, and beyond. The components of the test solution separate out, in rings, as the solvent progressively soaks the paper. Covering the apparatus with a bowl or jar (C) helps prevent evaporation of the solvent before it has had time to soak the paper.

(ii) The experiment continues until the solvent front reaches to within about 1 cm of the edge of the paper, or until it is apparent that it has stopped moving. The paper is then removed from the apparatus and rapidly dried, using the drying lamp (IX/A3), a fan, or other source of dry heat or moving air.

A3. Horizontal Paper Chromatography Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Paper	1	Filter Paper (A)	Approximately 10 cm diameter or larger
	1	String (B)	Approximately 0.2 cm diameter, 5-10 cm long
(2) Support	1	Cup or Jar (C)	Slightly smaller than filter paper (A)
(3) Cover	1	Glass Bowl or Jar (D)	To cover paper (A) and support (C)

b. Construction

(1) Paper

Take a circle or square of filter paper (A) or suitable substitute and cut several slits radiating from the center as shown. Punch a small hole in the center and secure a piece of string (B) with a knot, to act as a wick.

(2) Support

Select a small cup or jar (C) just slightly smaller than the paper (A). Rest the paper (A) on the rim of the jar (B) so that the string wick (C) extends into the jar.

(3) Cover

Select a large glass jar or bowl (D) to cover the support and paper. Invert the cover to enclose the other components.

c. Notes

(i) This apparatus is used in the same fashion as the preceding device. However, the slits in the paper allow for more than one colored substance or test solution to be used simultaneously. The spots are placed inside the "V" of the slits, which prevent the colors from merging.

A4. Vertical Paper Chromatography Equipment

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Paper	1	Chromatography Paper (A)	Approximately 15 cm x 15 cm
(2) Solvent	1	Beaker, Bowl or Jar (C)	To contain paper (A) when rolled into tube
(3) Cover	1	Glass Jar or Bowl (D)	To fit on or over Solvent Container (C)

b. Construction

(1) Paper

With a pencil, draw a faint line approximately 2 - 3 cm from one edge of the paper (A). Use this line as a guide for locating the spots of solution or solutions to be tested. Make the spots as small as possible and about 2 cm apart.

Roll the paper (A) loosely into a tube. Secure the edges together with the paper clips (B) such that the edges do not touch or overlap.

(2) Solvent Container

Set the rolled paper (A) into the beaker, bowl, or jar (C) and pour solvent into the container (C) to a height of about 1 cm.

(3) Cover

Rest a large glass jar or bowl (D) on or over the solvent container (C) to prevent evaporation of the solvent.

c. Notes

(i) If chromatography paper is not available, white paper toweling or blotting paper may be substituted.

(ii) When this apparatus is in use, the solvent front migrates up the paper, (by capillary action) resulting in the separation of the components of the test spot. This is allowed to continue until it has reached to within several cm of the top of the paper or until it is apparent that the solvent front will move no further (when the rate of capillary action is in equilibrium with the rate of evaporation). The paper is then removed from the apparatus and dried, and the final locations of the color spots may be circled with pencil for easy identification.

(iii) This apparatus is also suitable for performing separation of colorless substances, as long as the completed chromatogram can be treated in some way to make visible the final location of the component of the substances. For example, proteins, while generally colorless, may separate in this fashion. The dried chromatogram is then sprayed with a ninhydrin solution, which reacts with the amino acids in their final locaticns, making them visible as bluish spots or smudges.

(iv) It is possible, with this apparatus, to submit a substance to chromotographic separation by two different solvents on the same sheet of paper. To run such a two-dimensional chromatogram, a spot of the substance is placed at the intersection of two lines drawn on the paper and treated as described above, with one solvent. At the end of the first run, the chromatogram is removed from the apparatus and dried.

Then the paper is rotated 90° and again rolled into a tube, with the first separation at the bottom edge of the tube. This tube is run a second time with a second solvent. Thus, it is possible to effect a more complete separation than is possible with one solvent alone.

(v) A complete discussion of techniques and substances appropriate to chromatographic separation is beyond the scope of this guidebook. For further information, texts and resources on biochemistry, chemistry, and chromatography should be consulted.

A5. Vertical Strip Paper Chromatography Equipment

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Frame	2	Wood (A)	1 cm x 1 cm x 8 cm
	2	Wood (B)	1 cm x 1 cm x 10 cm
	4	Wood (C)	1 cm x 1 cm x 20 cm
	1	Wood or Masonite (D)	6 cm x 10 cm x 0.2 cm
	1	Thin, Stiff Wire (E)	Approximately 11 cm long
(2) Solvent	1	Cup or Jar (F)	Approximately 4 cm high, to fit inside frame
(3) Cover	1	Plastic Bag (G)	To fit loosely over frame

b. Construction

(1) Frame

(E)
(D)
(C)
(A)
(B)

With nails and glue, secure the frame parts (A), (B), (C), and (D) as shown. Secure the wire (E) to the frame, about 2 cm from the top, with two small nails.

(2) Solvent Container

Select a shallow cup or jar (F) that will fit inside the frame. If necessary, cut a tall jar down to a height of 3 - 4 cm (I/F2).

(3) Cover

Select a plastic bag (G) that will fit loosely over the frame. It may be held in place by clipping it with a clothespin to a clamp or ring that is supported about 10 cm above the frame on the ring and burette stand (IV/B5) or other suitable support. Alternatively, a frame to support the bag may be constructed out of stiff (e.g., coat hanger) wire.

c. Notes

(i) This frame may be used to support a strip of chromatography paper or suitable substitute for either ascending or descending chromatographic operations.

For ascending operations, the solvent container (F) remains at the bottom of the frame. The Paper strip, with one end just touching the solvent, is hung from the wire with a paperclip The spot or spots of substance to be separated is located at the lower end of the strip, just above the solvent. The apparatus should be kept covered by the plastic bag (G) during the course of the experiment to keep solvent evaporation to a minimum.

(ii) In order to use the frame for descending operations, the solvent container (F) is placed on the top shelf (D). The paper strip is then hung from the solvent container, held in place with a paper clip or clothespin, and with a short piece folded over to dip into the solvent. The spot is located near the top of the strip, outside the solvent container. The solvent front then moves down the paper in the course of the experiment.

(iii) If a sufficiently large jar is available, it may be used as a cover in place of the plastic bag (G).

B. QUANTITATIVE CHROMATOGRAPHIC EQUIPMENT

B1. Liquid-Column Apparatus

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Column	1	Glass Tube (A)	Approximately 1.5 cm outside diameter, 25 cm long
	1	Cotton or Glass Wool (B)	--
	1	1-Hole Stopper (C)	To fit tube
	1	Glass Tubing (D)	Approximately 0.5 cm diameter, 5-10 cm long
	--	Silica Gel (E)	28-200 mesh

b. Construction

(1) Column

Fire polish both ends of the glass tube (A) to eliminate sharp edges. Push a small wad of cotton or glass wood (B) about 1 cm into one end as a plug.

Insert the small glass tube (D) into the stopper (C) and push the stopper into the large glass tube (A), and support the column in a vertical position in a burette clamp (IV/B5) or other suitable support.

To pack the column with the stationary medium, make a slurry with several grams of the silica gel (E) and water. Pour this slurry into the top of the column, and allow the water to drain through the small glass tube (D), while the moist silica gel is retained by the plug (B). If necessary, pour additional slurry into the column until about 15 cm of the column is packed with silica gel and about 1 cm of water remains on top of the silica gel. If desired, the packing operation may be hastened by applying slight suction, by means of the suction-filter flask (VI/A4) coupled with a suction pump, aspirator (V/A8) or other source of suction.

c. Notes

(i) The flow of liquid through the column may be controlled, if desired, by the addition of a stopcock, or flexible rubber tubing coupled with a pinch clamp (IV/A4) or glass bead (III/B1). A glass nozzle may also be added to the free end of the flexible tubing.

(ii) To use this apparatus, the water remaining on the column is allowed to drain until less than 1 cm remains to cover the silica gel. Then a small quantity of a solution of colored material to be tested, in a concentrated form, is gently pipetted on to the medium. The desired solvent is then added to the column, and the column is allowed to drain slowly, using either gravity or very slight suction.

As the solvent moves down the column, carrying the substance with it, separation will occur, as indicated by colored zones appearing on the medium. As additional solvent is added to the column, the zones themselves will migrate down the column; if sufficient solvent is added, each zone, consisting of a specific component of the substance tested, may be washed off the column and recovered separately.

(iii) In addition to separating components of a substance and washing them down the column with one solvent, it is possible to use additional solvents to wash down a component or components that do not migrate at all with the first solvent. To do this, allow the column to drain until less than 1 cm of the first solvent remains on top of the medium, then add the second solvent to the column and proceed with the washing as described above.

(iv) Other interesting results may be obtained by reversing the order of solvents used, in successive runs, with the same test substance. For example, alcohol and water are two solvents that may be used, in either order, to separate a mixture of vegetable dyes or ink.

(v) One of the chief advantages of the liquid-column method of chromatographic

separation over paper chromatography is that the components of the substance tested are recovered individually for use in further experiments or in quantitative determinations. For example, a measured quantity of the test substance, in a known concentration, is added to the column, and the solvent used and the solutions recovered are measured. Then the components eluted are submitted to volumetric or gravimetric quantitative analysis to determine the proportion of each component present in the original sample.

(vi) Substances other than 28 - 200 mesh silica gel, and solvents other than alcohol or water, may be used in liquid-column chromatography. Further experimentation, as well as research into the technical literature on chromatography, is suggested for the development of this technique. A useful reference for this purpose is Erich Heftmann, Chromatography, Second Edition, (New York: Reinhold Publishing Corporation, 1967).

XII. MULTIPURPOSE SYRINGES

Many chemical techniques and experiments are readily performed using disposable plastic syringes. Some of these uses will be described in this section, and the devices have been grouped according to the concepts they illustrate. In addition to those uses given here, syringes can also be used in column chromatography, ion exchange devices, and other areas in chemistry.

A. TECHNICAL DEVICES

Two items of use in the chemistry laboratory are included here.

B. GAS STUDIES APPARATUS

Included here are several ways in which syringes may be used in studying the production, collection, and properties of gases.

C. DIFFUSION APPARATUS

Diffusion of both gases and liquids can easily be studied with the aid of plastic syringes.

D. OXIDATION APPARATUS

This section describes a number of devices used in the study of oxidation reactions.

E. ANALYTICAL APPARATUS

These devices are used in experiments to determine chemical formulae, structures, and molecular weight.

F. CONDUCTANCE APPARATUS

The variation in conductivity of different solutions can be studied with the aid of several devices which are fairly easily constructed with disposable syringes.

A. TECHNICAL DEVICES

A1. Dropper/Pipette

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringes	1	Plastic Disposable Syringe (A)	Capacity 10-50 ml

b. Construction

(1) Syringe

Select a calibrated, plastic disposable syringe (A) with a volume appropriate for the desired use.

c. Notes

(i) In the smaller sizes, disposable syringes make excellent droppers with an advantage being that the amount dispensed is measurable. Similarly, they can be used for the same purposes for which pipettes are used. In the larger sizes, syringes can substitute for burettes in titration experiments. Finally, syringes may be utilized in calibrating improvised flasks, beakers, etc., of unknown capacity.

(ii) Placing a medium-sized diameter needle (inside diameter approximately 0.03 cm) on the syringe nozzle will allow solutions to be carefully and accurately delivered, drop by drop.

A2. Pump

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity approximately 20 ml
(2) Connecting Tube	1	Plastic or Rubber Tubing (B)	Approximately 10 cm long, diameter to fit syringe nozzle (A)

b. Construction

(1) Syringe

Take a plastic, disposable syringe (A) with a volume appropriate for the desired use.

(2) Connecting Tubing

Attach a length of plastic or rubber tubing (B) to the syringe nozzle when the pump is to be used in hard-to-reach places.

c. Notes

(i) To use the pump, connect the tubing to the object from which gas or liquid is to be removed. Withdraw the plunger to draw gas or liquid into the syringe. Then remove the tubing from the object or container, direct the tubing into an appropriate container or waste receptacle, and depress the plunger to expell the gas or liquid through the tubing.

(ii) With two modifications, the syringe may be used to provide continuous pumping action without removing the tubing from the object from which substances are pumped. Make a small hole in the base of the syringe barrel with a drill or hot wire, and add a pinch clamp (IV/A4) to the tubing to close it off. In use, the tubing is connected to the object from which gas or liquid is to be removed. Then the pinch clamp is removed from the tubing and the hole in the syringe barrel is covered with a finger. The plunger is withdrawn to draw material into the syringe. To expell the contents of the syringe through the hole, the tubing is closed with the pinch clamp, the hole is uncovered, and the plunger is depressed.

B. GAS STUDIES APPARATUS

B1. Gas Production and Collection Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity 10-50 ml
(2) Connecting Tube	1	Rubber or Plastic Tubing (B)	2 cm long, diameter to fit syringe nozzle (A)
	1	Glass Tubing (C)	Approximately 0.5 cm diameter, 10 cm long
(3) Reaction Chamber	1	Hard Glass Test Tube or Flask (D)	Capacity 20-100 ml
	1	1-Hole Stopper (E)	To fit test tube or flask (D)

b. Construction

(1) Syringe

Select a plastic, disposable syringe (A) of appropriate capacity.

(3) Connecting Tubing

Connect the short piece of flexible rubber or plastic tubing (B) to the syringe nozzle.

Heat the glass tubing (C) sufficiently to bend it to a slight angle (about 30°). Connect

*Adapted from Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 19.

one end of the glass tubing to the rubber or plastic tubing (B).

(3) Reaction Chamber

Seal a hard glass test tube or flask (D) (capacity from 20 to 100 ml, depending on the desired use) with a one-hole stopper (E). Use a rubber stopper if caustic materials are to be used in the apparatus. Insert the free end of the glass tubing into the hole in the stopper.

c. Notes

(i) This simple reaction apparatus, suitable for either lecture demonstration or student laboratory use, may be employed in a number of ways. In the simplest qualitative experiments, the use of the syringe allows liquids to be introduced into the reaction chamber where they react with solids or other liquids. A number of gases can be produced using this or similar devices. For example, injecting a 3% solution of hydrogen peroxide from the syringe into a suspension of dried yeast and water in the test tube will yield oxygen gas. Also, injecting a concentrated solution of baking soda from the syringe into vinegar will yield carbon dioxide. Finally, injecting vinegar into water and a piece of magnesium ribbon will cause hydrogen gas to be liberated. The gas liberated will collect in the syringe, pushing the plunger out as more and more gas is given off. Turning the plunger slightly will assure that the gas is at atmospheric pressure.

(ii) This apparatus may also be used for quantitative studies in the above reactions. The solid reactants must be carefully weighed or measured, and the use of the syringe allows very precise amounts of liquids to be introduced into the reaction chamber. The volume of the gas evolved may be read from the syringe. The change in volume of gas in the syringe may be plotted against time to give a measure of the rate of reaction. In addition, the volume of gas liberated may also be plotted as a function of temperature and/or the concentration of one or more of the reactants used.

(iii) In a third type of experiment using this apparatus, solids which give off gases when heated are placed in the test tube, and the gas is collected in the syringe. Begin with the syringe plunger fully depressed, and as the gas is evolved, it will push the plunger back, giving a quantitative measure of the amount of gas produced. In using this device, clamps to hold both the test tube and syringe are needed. As an example, red lead can be heated in the test tube, and the gas

evolved collected in the syringe. It should be noted, however, that this will spoil the test tube. Instead, potassium permanganate can be used, and no spoilage of the test tube will occur. However, some asbestos wool must be put in the upper end of the test tube to prevent pieces of the potassium permanganate from entering the syringe.

(iv) The experiments based on the use of this apparatus are adapted from Nuffield O-Level Chemistry, Collected Experiments, (London: Longmans/Penguin Books, 1967), pp 9, 229-231, 297-299.

(v) If a glass reaction chamber is not available or is not desired, a second syringe, the same size as the first but slightly modified, may be substituted. First, with a hand drill or hot nail or wire, bore two holes, approximately 0.3 cm in diameter, opposite each other about halfway along the length of the barrel. With a drill and saw or hot nail, make a slit in the syringe plunger as shown. Push the plunger into the syringe, and lock it in place by inserting a nail approximately 0.3 cm wide and 5 cm long through the holes in the barrel and slit in the plunger. Place in the lower syringe a small piece of material which will react with the liquid to be placed in the upper syringe. Replace the plunger in the lower syringe, insert the nail stop, and depress the plunger until the nail prevents further movement. Draw a quantity of liquid into the upper syringe, and fasten the two together with the short piece of tubing. Next, inject all of the liquid into the lower syringe and

leave the upper syringe plunger in the depressed position. As gas is given off in the lower syringe, it will expand and push out the plunger of the upper syringe until the upper syringe is filled with gas or the reaction stops. Solids and liquids which can be used as outlined to produce gases include animal charcoal and hydrogen peroxide (to form oxygen), metals and dilute acids, carbonates and acids.

(vi) The above modification is based on a design by Andrew Farmer, "The Disposable Syringe--A Rival to the Test Tube?," School Science Review, CLXXIV (1969), 30-31.

B2. Micro-Generator *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Disposable Plastic Syringe (A)	Capacity 10-50 ml
(2) Beaker	1	Glass Jar or Beaker (B)	To accommodate syringe as shown

b. Construction

(1) Syringe

Select a plastic, disposable syringe (A) of a size appropriate to the amount of gas desired.

(2) Beaker

Select a glass jar or beaker (B) such that the syringe can be rested in it more or less vertically.

c. Notes

(i) As an example of its use, the micro-generator can be employed to generate hydrogen sulphide gas (H_2S). Simply place a small piece of ferrous sulphide in the syringe, and put a small amount of dilute hydrochloric acid in the beaker. Draw a portion of the acid up into the syringe until it touches the ferrous sulphide, and leave the syringe resting in the beaker. The gas will collect in the syringe, above the acid. If desired, the needle may be reattached to the syringe when it comes time to bubble the gas through a test solution.

*Adapted from L. A. George, "Two Further Uses for Disposable Syringes," School Science Review, CLXX (1968), 113.

B3. Gas Solubility Device/Reaction Rate Chamber

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity approximately 25 ml
(2) Plug	1	Nail (B)	To fit syringe nozzle (A)

b. Construction

(1) Syringe — Take a plastic, disposable syringe (A) of 25 ml or other desired capacity.

(2) Plug — Use the nail (B) to completely seal the syringe after a substance has been drawn into it.

c. Notes

(i) A number of simple solubility experiments may be done with syringes that can be sealed airtight. For example, the syringe may be half filled with cold water, with the plunger just above the water level. Seal the nozzle, and when the plunger is withdrawn further, air will be seen to bubble out of the water. This same demonstration may be repeated with distilled water, or cold water through which CO_2, O_2, N_2, etc., have been bubbled. A slightly more sophisticated demonstration involves water through which CO_2 has been bubbled for about five minutes. When a small amount of bromothymol blue is added, the solution will be yellow. Add this to a sealed syringe, and as the plunger is withdrawn, CO_2 will bubble out and the color of the solution will change to pale green. If the syringe is shaken,

the CO_2 will be redissolved, and the solution will once again be yellow. The experiment may be tried repeatedly.

(ii) A single syringe can also be used to illustrate the effect of pressure on solubility. Attach a short length of rubber tubing to the nozzle, and also attach a clamp or piece of wire to the rubber tube which can be used to close the tube. Fill the syringe half full of water, and fill the remainder of the barrel with CO_2. Shake the syringe vigorously, then hold the tube under water, release the clamp (or loosen the wire), and note the rise in water level in the syringe. Repeat the experiment, but depress the syringe plunger while shaking it. There will be a noticeable difference in the rise of the water level.

(iii) The above experiments have been adapted from Andrew Farmer, "The Disposable Syringe--A Rival to the Test Tube?," School Science Review, CLXXIV (1969), 35-37.

(iv) Another experiment that can be performed with the sealed syringe involves the relationship between reaction rate and pressure. Fill the syringe partially with vinegar and add sodium bicarbonate. Carbon dioxide will be given off, and this reaction can be speeded up or slowed down and stopped by decreasing or increasing the internal pressure with the plunger, respectively. This experiment is based on Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 6.

B4. Charles' Law: Volume/Temperature Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity 35 ml
	1	Small Eyed Screw (B)	To seal syringe nozzle (B)
(2) Weight	1	Lead Sinker or Weight (C)	Approximately 30 g

b. Construction

(1) Syringe

Make two small holes in the bottom of the syringe barrel (A) with a hand drill or hot wire.

*Adapted from Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 32.

Screw a small, eyed screw (B) into the syringe nozzle to seal the nozzle and to provide an attachment for the weight (C).

(2) Weight

Hang a lead sinker (C) or other suitably sized weight (approximately 30 g) from the eyed screw.

c. Notes

(i) With the plunger set so that a 35 cc volume of air is trapped in the syringe barrel, the device is put into a container of hot water. Water will be seen to enter the syringe barrel as the expanding air leaves it through the small holes (the effect will be more visible if a drop of vegetable dye is placed in the nozzle depression before beginning). Varying amounts of water will enter the syringe depending upon the water temperature. Good quantitative data can be gotten by comparing the water temperature with the amount of water entering the syringe (or the air volume of the syringe after the water enters). The device should be removed from the water to return the air volume to its original reading for each temperature/pressure reading.

C. DIFFUSION APPARATUS

C1. Liquid Diffusion Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity approximately 50 ml

b. Construction

(1) Syringe

Select a plastic, disposable syringe (A) of a large capacity (35 - 50 ml, for example).

c. Notes

(i) To use this device to study diffusion of liquids, fill the syringe almost completely with cold water. Then, draw a small amount of colored solution into it and let the syringe stand. Diffusion should be complete after two or three days. Colored solutions which work well include potassium permanganate and copper sulphate.

(ii) This experiment has been adopted from Andrew Farmer, "The Disposable Syringe: Additional Experiment," School Science Review, CLXXVIII (1970), 60.

C2. Gas Diffusion Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Gas Container	1	Plastic Disposable Syringe (A)	Capacity approximately 25 ml
(2) Connecting Tubing	1	Rubber or Plastic Tubing (B)	Approximately 15 cm long, diameter to fit syringe nozzles
	1	Pinch Clamp (C)	IV/A4
(3) Indicator Container	1	Plastic Disposable Syringe (D)	Capacity approximately 25 ml
	--	Indicator Solution (E) (Limewater or Litmus Solution)	Approximately 5 ml

*Adapted from Andrew Farmer, "The Disposable Syringe--A Rival to the Test Tube?," School Science Review, CLXXIV (1969), 35.

b. Construction

(1) Gas Container — Select a plastic, disposable syringe (A) of about 25 ml capacity.

(2) Connecting Tubing — Use a length of flexible tubing (B) to connect the two syringes together. Make a pinch clamp (C) or use another suitable clamp to close the tubing.

(3) Indicator Container — Select a plastic, disposable syringe (D) with the same capacity as that used for the gas container. Fill it with the indicator solution (E).

c. Notes

(i) Place an indicator solution (e.g., limewater) in the indicator container. A gas (e.g., CO_2) is collected in the gas container syringe and the two syringes are connected by the tubing. When the clamp is released, the gas will diffuse until it reaches the indicator solution and causes a reaction (white precipitate when CO_2 meets limewater). The time taken for the gas to diffuse may be measured.

(ii) A slight modification of the indicator container will allow a comparison of gas diffusion rates in air and in a partial vacuum. This is done by making two holes opposite each other near the mouth of the syringe barrel with a hand drill or heated nail. Then one hole is made in the plunger, as shown. The holes should be made so that a nail can be pushed through the barrel and plunger.

To repeat the above experiment with a partial vacuum, the nail is removed from the indicator syringe and several ml of indicator solution are drawn into the syringe. Then the tubing, closed by the clamp, is attached to the syringe. With the clamp in place the plunger is pulled back, to create a partial vacuum, and the nail is pushed through the syringe barrel and plunger to hold the plunger in position. Gas is collected in the other syringe and allowed to diffuse to the indicator solution, and the time taken is compared to the results of the first experiment.

D. OXIDATION APPARATUS

D1. Oxidation Indicator: Membrane Type *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe Assembly	1	Plastic Disposable Syringe (A)	Capacity 25-50 ml
	1	Nail (B)	Approximately 0.2 cm diameter, 4 cm long
(2) Membrane	1	Thin Sheet Rubber (C)	Approximately 5 cm x 5 cm
	1	Rubber Band or Thin Wire (D)	--

b. Construction

(1) Syringe Assembly

Take a medium to large capacity (25 - 50 ml) plastic, disposable syringe (A). Cut off the end of the barrel near the nozzle. Then, with a hand drill or hot nail, make two holes approximately 0.3 cm in diameter opposite each other near the mouth of the barrel.

In the same fashion, make one hole in the stem of the plunger, near the plug, as shown.

*Adapted from Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 6.

Insert the plunger into the syringe barrel, and push the nail (B) through the holes in the barrel and plunger to fix the plunger in position.

(2) Membrane

Cut a 5 cm x 5 cm square of thin sheet rubber (C) (from a toy balloon, for example). Stretch it over the open end of the syringe barrel and secure it in place with a rubber band (D) or length of thin wire.

c. Notes

(i) This simple device will give a visual indication that oxidation is taking place. For example, if wet steel wool or a piece of cotton soaked in alkaline pyrogallol [Note (i) XII/D4] is inserted into the barrel of the syringe and the plunger fixed in place with the nail, as the material reacts with the oxygen in the air the pressure inside the syringe will gradually be lowered. This can be seen since the rubber sheet will be pulled further and further into the syringe.

D2. Oxidation Indicator: Displacement Type *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity approximately 35 ml
(2) Beaker	1	Jar or Beaker (B)	To support syringe

b. Construction

(1) Syringe

Select a plastic, disposable syringe (A) of medium to large capacity (35 - 50 ml). No modifications are necessary.

(2) Beaker

Choose a small glass jar (B), beaker, or other container that will support the syringe, as shown.

c. Notes

(i) Place a portion of wet steel wool (it may have to be washed in vinegar to remove the anti-rust coating) in the syringe barrel and position the plunger

*Adapted from Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 2.

so that some predetermined air volume is trapped in the syringe. Place the syringe into a small amount of water in the beaker so that the nozzle is under water. As the steel wool reacts with the oxygen in the air, pressure inside the syringe will drop and water will be drawn up into the syringe barrel. Dyeing the water with non-fast vegetable dye will make the visual display more evident.

Cotton wool or other absorbent material soaked with alkaline pyrogallol [Note (i) XII/D4] may be substituted for the wet steel wool.

D3. Oxidation Rate Indicator *

(1) Indicator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Indicator	1	Respirometer	BIOL/VIII/D1(1)

b. Construction

(1) Indicator

Construct this item according to directions given for the Respirometer, BIOL/VIII/D1(1).

c. Notes

(i) Begin operation of this device by fastening the plastic tubing to the reservoir and to the nozzles of the syringes. Fill the reservoir with water which has been colored with non-fast vegetable dye. Items which react with oxygen in the air, including wet steel wool, white phosphorus, or alkaline pyrogallol (soaked cotton wool), are placed in the barrel of one syringe, where they react, removing oxygen from the trapped air. This results in a lowering of pressure which causes the colored water to be drawn from the reservoir into the clear tubing. The second syringe serves as a control, containing only air. The rate of the reaction can be judged from the speed with which the water column moves toward the syringe.

*Adapted from Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 11.

D4. Stoichiometry Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Capacity 10 ml or more
(2) Connecting Tube	1	Rubber or Plastic Tubing (B)	To fit syringe
	1	Glass Tubing (C)	0.5 cm diameter, 2 cm long
(3) Glass Tube	1	Glass Tubing (D)	2-3 cm diameter, 10 cm long
	1	1-Hole Stopper (E)	To fit large tubing
	--	Cotton (Cotton Wool) (F)	--
(4) Water Container	1	Pan or Tray (G)	Capacity approximately 1 liter

*From Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 19.

b. Construction

(1) Syringe

Select as many plastic, disposable syringes (A) of the same capacity (approximately 10 ml) as desired.

(2) Connecting Tubing

Connect the short rubber or plastic tubing (B) to the syringe nozzle. Connect the free end of the rubber or plastic tube to the short piece of glass tubing (C).

(3) Glass Tubing

Seal one end of a large diameter glass tube (D) with a one-hole stopper (E) and insert the glass tube (C) into the hole in the stopper.

Push a small wad of cotton (F) (cotton wool) into position near the top of the glass tube, below the stopper.

(4) Water Container

For the water container, use a pan, tray, jar, or beaker (G) into which the desired number of syringe assemblies can be filled.

c. Notes

(i) An alkaline pyrogallol solution must be prepared for use with this apparatus. Put 10 g powdered pyrogallol [1, 2, 3 -- trihydroxybenzene, $C_6H_3(OH)_3$] and 2 g sodium hydroxide (NaOH) pellets into a small flask or test tube. Add about 30 ml H_2O. Tightly cap the container and shake it until all the solid dissolves. Avoid stirring the container to introduce air, as the alkaline solution will rapidly absorb oxygen and become useless for the experiment.

(ii) For experimentation in stoichiometry, several of these syringe assemblies need to be set up. Each should have an identical amount of the pyrogallol solution (or other reducing agent) in the syringe. Place all the devices open

end down in the water container. Inject varying amounts of the pyrogallol (for example, 0.5, 1, 1.5 ... 10 ml) into the glass tube where it will be absorbed in the cotton. The pyrogallol will then react with the oxygen in the air in the tube, and continue to react until either the pyrogallol or oxygen is consumed. As oxygen is removed from the air, pressure in the tube will fall, and water will be drawn up into it from the trough. The height of the water in the tube then becomes a measure of the amount of oxygen consumed, and will be seen to be proportional to the amount of pyrogallol used, until the upper limit is reached.

(iii) If glass tubes are not available, syringe barrels may be substituted. A short piece of plastic or rubber tubing is used to connect the upper syringe and lower syringe barrel, which is used in an inverted position.

E. ANALYTICAL APPARATUS

E1. Air Composition Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe and Tubing	2	Stoichiometry Device (A)	XII/D4, Components (1), (2), and (3)
(2) Water Container	1	Pan or Tray (B)	Approximately 1 liter
	--	Limewater (C)	--
	2	Modeling Clay (D) (Plasticine)	Small wads
	2	Candles (E)	Approximately 0.5 cm diameter, 5 cm long

*From Paul D. Merrick, Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968), p 20.

b. Construction

(1) Syringe and Tubing

Prepare two syringe and tubing (A) assemblies, as described for the Stoichiometry Device (XII/D4).

(2) Water Container

Support each candle (E) in a small wad of modeling clay (D), about 5 - 10 cm apart on the bottom of the pan or tray (B). The clay wad must be smaller than the diameter of the glass tube used.

Pour sufficient limewater (C) into the pan or tray to cover the wad of clay and 1 cm or so of the candles.

c. Notes

(i) To investigate the proportion of oxygen in the air, an alkaline pyrogallol solution, prepared according to instructions in XII/D4, is required. Each syringe should contain an equal amount of the pyrogallol solution (5 ml, for example).

(ii) When the syringe assemblies, with alkaline pyrogallol solution in each syringe, and the candles in the limewater have been prepared, light one candle. After a few seconds, place one of the syringe assemblies over each candle. Allow them to stand for about five minutes after the burning candle goes out to allow the limewater to remove CO_2 from the air in its tube. At this time, limewater will have risen into the tube to compensate for the lost CO_2. Mark this level of limewater with a wax pencil or felt-tipped marker.

Using a syringe pump (see XII/A2), remove air from the other tube until the limewater rises to the same level in the second tube as it had in the first. Mark this level, also. Now, inject alkaline pyrogallol from the syringes onto the cotton wads. This will react with the oxygen in the air, and remove all of it if enough pyrogallol is used. The water level in each tube will have risen. The amount of rise in the first tube (the one containing the candle) will be compared to the amount of rise in the second tube. Also, the change in trapped air volume in both tubes should be noticed. By doing this, it will be found from the first tube that the burning candle removes only about 25% of the oxygen in the air, while the change in volume in the second tube will show that air is about 21% oxygen.

E2. Gas Reaction Chamber *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	2	Plastic Disposable Syringe (A)	Capacity 50 ml
(2) "T" Tube	1	Glass "T" Tube (B)	Approximately 0.5 dm diameter
(3) Tubing	3	Rubber Tubing (C)	To fit syringe nozzle, approximately 8 cm long
(4) Clamp	3	Pinch Clamp (D)	IV/A4

b. Construction

(1) Syringe

Select two 50 ml plastic, disposable syringes (A). Secure the syringes in a horizontal position by appropriate supports.

(2) "T" Tube

Use a glass or metal "T" tube (B) with three outlets. If available, a three-way valve (stopcock) may be substituted for the clamps and "T" tube.

*Adapted from Nuffield O-Level Chemistry, Collected Experiments, (London: Longmans/ Penguin Books, 1967), p 237.

(3) Tubing

Connect the two syringes to the "T" tube with two short pieces of rubber tubing (C). Use a third piece of tubing (C) to connect the apparatus to a source of gas.

(4) Clamp

Use three pinch clamps (D) or other suitable clamps to close each section of tubing.

c. Notes

(i) To determine the number of gram-molecules of hydrogen chloride that react with one gram-molecule of ammonia, set up the apparatus as shown in the main illustration. Using the correct combination of open and closed clamps, fill one syringe with dry ammonia gas, empty it, and repeat one or two more times to "flush" the syringe. Follow the same procedure with the other syringe using dry hydrogen chloride. Then, fill the first syringe with 40 cc of the dry ammonia and fill the second with 50 cc of the dry hydrogen chloride. With the two syringes open to each other but closed to the atmosphere, inject the hydrogen chloride into the syringe of ammonia. The two gases will react, forming ammonium chloride. That about 10 cc of hydrogen chloride remains unreacted is shown by passing the gas over damp indicator paper. Thus, 40 cc of ammonia reacts with 40 cc of hydrogen chloride.

F. CONDUCTANCE APPARATUS

F1. Conductance Device *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Injecting Syringe	1	Plastic Disposable Syringe (A)	Capacity approximately 35 ml
(2) Receiving Syringe	1	Plastic Disposable Syringe (B)	Capacity approximately 35 ml
(3) Wire	2	Insulated Wire (C)	Approximately 0.3 cm diameter, 50 cm long
(4) Tubing	1	Plastic or Rubber Tubing (D)	To fit syringe nozzles, 2 cm long

b. Construction

(1) Injecting Syringe

Use a 35 ml plastic, disposable syringe (A), with no modifications, for this component.

*Adapted from Andrew Farmer, "The Disposable Syringe--A Rival to the Test Tube?," School Science Review, CLXXIV (1969), 32-34.

(2) Receiving Syringe

Take a 35 ml plastic, disposable syringe (B) and with a hand drill or hot wire make two holes, approximately 0.2 cm in diameter, opposite each other near the base of the barrel.

(3) Wire

Epoxy Glue Seal

Remove about 1.0 cm of insulation from each end of both wires (C). Insert one bare end of each wire through the holes in the syringe barrel (B). Seal the holes with epoxy glue, taking care to see that no epoxy covers the bare wire inside the syringe barrel.

(4) Tubing

Connect the two syringes together with a short piece of plastic or rubber tubing (D).

c. Notes

(i) This apparatus may be used to investigate the variation of conductance as two solutions are mixed. The wires are connected in series to a 1.5 volt cell and an ammeter as shown. One liquid is placed in the receiving syringe, another in the injecting syringe, and the current is measured on the ammeter. Then the solution in the injecting syringe is gradually fed into the receiving syringe, and any changes in the current are noted. Conductance, the reciprocal of resistance, may be calculated from the

current and voltage:

$$R = \frac{E}{I} \qquad \text{mhos} = \frac{1}{R}$$

(ii) Solutions which may be tested in this apparatus include water in the receiving syringe and salt solution or HCl solution in the injecting syringe; dilute H_2SO_4 in the receiving syringe and $Ba(OH)_2$ solution in the injecting syringe; and dilute HCl in the receiving syringe with NaOH in the injecting syringe.

(iii) This device, with one modification, may also be used to investigate the variation of conductance as a gas is bubbled into a solution. The injecting syringe is removed and replaced with a section of plastic or rubber tubing that connects the remaining syringe to a gas source. For example, the syringe is filled with a limewater solution, and the current is noted on the ammeter. Then CO_2 is passed through the limewater, and the change in current as well as the change in color of the solution can be seen. Phenolphthalein can also be added to the limewater initially, and the color change from red to clear will indicate the neutralization has occurred.

F2. Constant Volume Conductance Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Jar with Lid (A)	Capacity approximately 200-250 ml
(2) Extracting Syringe	1	Plastic Disposable Syringe (B)	Capacity approximately 20 ml
	1	Rubber or Plastic Tubing (C)	Diameter to fit syringe nozzle; length, about 1 cm shorter than jar height

(3) Injecting Syringe	1	Plastic Disposable Syringe (D)	Capacity approximately 20 ml
(4) Wire	2	Insulated Wire (E)	Diameter 0.3 cm, 50 cm long

b. Construction

(1) Container

Puncture four holes in the jar lid (A). Make the two outside holes about 0.5 cm in diameter to accommodate the syringe (B,D) nozzles. Make the two inner holes about 1 - 2 cm apart and 0.4 cm in diameter, to accommodate the insulated wire (E).

(2) Extracting Syringe

Push the nozzle of a plastic, disposable syringe (B) through one of the outer holes in the jar lid. Attach the rubber or plastic tubing (C) to the syringe nozzle from the inside of the lid.

(3) Injecting Syringe

Push the nozzle of a second plastic, disposable syringe (D) through the other outer hole in the jar lid.

(4) Wire

Strip 5 - 7 cm of insulation from one end of each wire (E). Push each stripped end of wire through the inner holes in the jar lid, from the outside of the lid. Allow about 8 - 9 cm of each wire to extend from the inside of the lid.

c. Notes

(i) In order to use this apparatus to investigate variations in the conductance of a solution as its composition (but not its volume) is changed, the wires from the container must be connected, in series, to a 1.5 volt battery and an ammeter. [See diagram, Note (i), XII/F1.] A solution, such as water, is placed in the container. A second solution (concentrated salt solution, for example) is placed in the injecting syringe and the lid placed on the jar. Current is measured; then a measured amount of solution from the injecting syringe is added to the container, the solution mixed well, and volume of solution equal to that added to the container is withdrawn with the extracting syringe so that the electrode depth is unchanged. Current is again measured, and conductance calculated as described in Note (i), XII/F1.

(ii) This equipment is adopted from Andrew Farmer, "The Disposable Syringe--A Rival to the Test Tube?," School Science Review, CLXXIV (1969), 34-35.

BIBLIOGRAPHY

A number of texts have proved to be extremely valuable references to the Inexpensive Science Teaching Equipment Project, and these are listed below.

American Peace Corps, Science Teachers' Handbook, (Hyderabad, India: American Peace Corps, 1968).

This handbook contains many ideas for improvising science teaching equipment.

Association for Science Education, The School Science Review, (London: John Murray).

A quarterly journal containing articles on science experiments and equipment in all the sciences at all school levels.

Association for Science Education, The Science Master's Book, Part 2 (Chemistry) Series 1-4, (London: John Murray).

These materials, selected from The School Science Review, describe apparatus and experiments for a wide range of chemistry activities.

Coulson, E. H., A. E. J. Trinder, and Aaron E. Klein, Test Tubes and Beakers: Chemistry for Young Experimenters, (Garden City, New York: Doubleday and Company, Inc., 1971).

This book describes simple apparatus and experiments for youngsters in a home laboratory.

Bowker, M. K., and A. R. D. Hunt, Making Elementary Science Apparatus, a Handbook for Teachers in Tropical Areas, (London: Thomas Nelson and Sons, Ltd., 1968).

This book outlines instructions for construction and use of inexpensive, elementary science apparatus.

The Portland Project Committee, Teacher Guide, Chemistry of Living Matter, Energy Capture, and Growth, (Portland, Oregon, U.S.A.: The Portland Project Committee, 1971).

This guide is one of a three-year sequence integrating biology, chemistry, and physics into one secondary science program. Student guides are also available.

Richardson, John S., and G. P. Cahoon, Methods and Materials for Teaching General and Physical Science, (New York, Toronto, and London: McGraw-Hill Book Company, Inc., 1951).

This guide describes investigations and laboratory techniques for secondary level physics and chemistry.

United Nations Educational, Scientific, and Cultural Organization, UNESCO Source Book for Science Teaching, (Paris: UNESCO, 1962).

This book, recently revised, contains many simple ideas for teaching science at a relatively elementary level.

In addition to the above texts, the materials from a large number of projects in the files of the International Clearinghouse on Science and Mathematics Curricular Developments at the University of Maryland have also been particularly valuable. Further details of these projects may be found in:

The Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments, 1970. (College Park, Maryland, U.S.A.: University of Maryland, 1970).

This is a source of information on curriculum projects throughout the world, and indicates materials available, project directors, publishers, etc. The Eighth Report will be available in late 1972.

GUIDEBOOK TO CONSTRUCTING INEXPENSIVE SCIENCE TEACHING EQUIPMENT

Volume III: Physics

Inexpensive Science Teaching Equipment Project
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FOREWORD

History

The Inexpensive Science Teaching Equipment Project was initiated by Dr. J. David Lockard, and got underway under his direction in the summer of 1968. Originally entitled the Study of Inexpensive Science Teaching Equipment Worldwide (IS-TEW or IS-2 Study), the Project was to (1) identify laboratory equipment considered essential for student investigations in introductory biology, chemistry and physics courses in developing countries; (2) improvise, wherever possible, equivalent inexpensive science teaching equipment; and (3) produce designs of this equipment in a Guidebook for use in developing countries. Financial support was provided by the U.S. Agency for International Development through the National Science Foundation.

The initial work of the Project was undertaken by Maria Penny and Mary Harbeck under the guidance of Dr. Lockard. Their major concern was the identification of equipment considered basic to the teaching of the sciences at an introductory level. An international survey was conducted, and a list of equipment to be made was compiled. A start was also made on the writing of guidelines (theoretical designs) for the construction of equipment.

Work on the development of the Guidebook itself got underway in 1970, with the arrival of Reginald F. Melton to coordinate the work. Over 200 guidelines were completed during the year by Donald Urbancic (Biology), Chada Samba Siva Rao and John Delaini (Chemistry), and Reginald Melton (Physics). Full use was made of project materials from around the world which were available in the files of the International Clearinghouse on Science and Mathematics Curricular Developments, which is located in the Science Teaching Center of the University of Maryland. The guidelines were compiled into a draft edition of the Guidebook which was circulated in September, 1971, to some 80 science educators around the world for their comments and advice.

The work of constructing and developing equipment from the guidelines, with the subsequent production of detailed designs, began in a limited way in 1970, the major input at that time being in the field of chemistry by Chada Samba Siva Rao, who was with the project for an intensive two-month period. However, the main work of developing detailed designs from the guidelines was undertaken between 1971 and 1972 by John Delaini (Biology), Ruth Ann Butler (Chemistry) and Reginald Melton (Physics). Technical assistance was given by student helpers, with a special contribution from David Clark, who was with the project for a period of 18 months.

Thanks are due to those graduates, particularly Samuel Genova, Melvin Soboleski and Irven Spear, who undertook the development of specific items of equipment while studying at the Center on an Academic Year Institute program; to student helpers, especially Don Kallgren, Frank Cathell and Theodore Mannekin, who constructed the equipment; and to Dolores Aluise and Gail Kuehnle who typed the manuscripts.

Last, but not least, special acknowledgement is due to those individuals, and organizations, around the world who responded so willingly to the questionnaires in 1968 and to the draft edition of the Guidebook in 1971.

<u>The Guidebook</u>

The designs presented in the Guidebook are based on the premise that many students and teachers in developing countries will wish to make equipment for themselves. This does not mean that students and teachers are expected to produce all their own apparatus requirements. It is recognized that teachers have specific curricula to follow, and that "class hours" available for such work are very limited. It is also recognized that teachers, particularly those in developing countries, are not well paid, and often augment their salaries with supporting jobs, thus placing severe limits on the "out-of-class hours" that are available for apparatus production.

However, in designing equipment for production by students and teachers, two factors have been kept in mind. One, project work in apparatus development can be extremely rewarding for students, bringing both students and teachers into close contact with the realities of science, and relating science and technology in the simplest ways. Two, it is not difficult for cottage (or small scale) industries to adapt these designs to their own requirements. The Guidebook should therefore not only be of value to students and teachers, but also to cottage industries which may well be the major producers of equipment for schools.

Although all the designs in the Guidebook have been tested under laboratory conditions in the University of Maryland, they have not been tested in school situations nor produced and tested under local conditions in developing countries. It is therefore recommended that the designs should be treated primarily as limited resource materials to be subjected to trial and feedback. It is suggested that the first time that an item is constructed it should be made precisely as described in the Guidebook, since variations in the materials, or the dimensions of the materials, could alter the characteristics of the apparatus. However, once this item has been tested the producer is encouraged to make any number of modifications in the design, evaluating the new products against the original.

Before producing new equipment in quantity, it is recommended that educators with experience in the field of science education should be involved in determining how best to make use of the Guidebook. They will wish to relate the apparatus to their own curriculum requirements, and, where necessary, prepare relevant descriptions of experiments which they recommend should be undertaken using the selected apparatus. They will want to subject the experiments and related equipment to trials in school situations. Only then will they consider large-scale production of apparatus from the designs in the Guidebook. At this stage educators will wish to control the quality of apparatus production, to train teachers to make the best use of the new apparatus, and to insure that adequate laboratory conditions are developed to permit full utilization of the apparatus. Too often in the past apparatus has sat unused on many a classroom shelf, simply because the teacher has been untrained in its usage, or the laboratory facilities have been inadequate, or because the apparatus available did not appear to fit the requirements of the existing curriculum. Such factors are best controlled by educators in the field of science education in each country. Clearly the science educator has a crucial role to play.

Apparatus development, like any aspect of curriculum development, should be considered as a never ending process. This Guidebook is not presented as a finished product, but as a part of this continuing process. There is no doubt that the designs in this book could usefully be extended, descriptions of experiments utilizing the apparatus could be added, and the designs themselves could be improved. No extravagant claims are made concerning the Guidebook. It is simply hoped that it will contribute to the continuing process of development.

TOOLS AND RAW MATERIALS

The raw materials required to make specific items of equipment are indicated at the beginning of each item description. However, there are certain tools and materials which are useful in any equipment construction workshop, and these are listed below.

Tools

Chisels, Wood

3, 6, 12, 24 mm
(i.e., 1/8", 1/4", 1/2", 1")

Cutters

Bench Shears: 3 mm (1/8")
Glass Cutter
Knife
Razor Blades
Scissors: 200 mm (8")
Snips (Tinmans), Straight: 200 mm (8")
Snips (Tinmans), Curved: 200 mm (*")
Taps and Dies: 3 to 12 mm (1/8" to 1/2") set

Drills and Borers

Cork Borer Set
Countersink, 90^{o}
Metal Drill Holder (Electrically Driven), Capacity 6 mm (1/4")
Metal Drills: 0.5, 1, 2, 3, 4, 5, 6, 7 mm
(i.e., 1/32", 1/16", 3/32", 1/8", 5/32", 3/16", 7/32", 1/4") set
Wood Brace with Ratchet: 250 mm (10")
Wood Augur, Bits: 6, 12, 18, 24 mm
(i.e., 1/4", 1/2", 3/4", 1")

Files, Double Cut

Flat: 100 mm, 200 mm (4", 8")
Round: 100 mm, 200 mm (4", *")
Triangular: 100 mm (4")

Hammers

Ball Pein: 125, 250, (1/4, 1/2 lb)
Claw 250 g (1/2 lb)

Measuring Aids

Caliper, Inside
Caliper, Outside
Caliper, Vernier (may replace above two items)
Dividers: 150 mm (6"), Toolmakers
Meter, Electrical (Multipurpose - volts, ohms, amps, etc.)
Meter Stick
Protractor
Scriber

Measuring Aids (Continued)

Set Square
Square, Carpenter's: 300 mm (12") blade
Spoke Shave: 18 mm (3/4")
Wood Smoothing Plane

Pliers

Combination: 150 mm(6")
Needle Nose: 150 mm (6")
Side Cutting: 150 mm (6")
Vise Grips

Saws, Metal

300 mm (.2") blades

Saws, Wood

Back Saw: 200, 300 mm (8", 12")
Coping Saw: 200 mm (8")
Cross Cut: 600 mm (24")
Hand Rip: 600 mm (24")
Key Hole Saw: 200 mm (8")

Screw Drivers

100 mm (4"), with 2 and 3 mm tips
150 mm (6"), with 5 mm tip
200 mm (8"), with 7 mm tip

Vises

Metal Bench Vise: 75 mm (3")
Wood Bench Vise: 150 mm (6")

Miscellaneous

Asbestos Pads
Goggles, Glass
Oil Can: 1/2 liter (1 pint)
Oil Stone, Double Faced
Punch, Center
Sandpaper and Carborundum Paper, Assorted grades
Soldering Iron: 60 watts, 100 watts

<u>Raw Materials</u>

Adhesives

All Purpose Cement (Elmers, Duco)
Epoxy Resin & Hardener (Araldite)
Rubber Cement (Rugy)
Wood Glue (Weldwood)
Cellophane Tape
Plastic Tape
Masking Tape

Electrical Materials

Bulbs with Holders: 1.2, 2.5, 6.2 volts
Dry Cells: 1.5, 6 volts
Electrical Wire: Cotton or Plastic covered
Fuse Wire: Assorted
Lamps: 50, 75, 100 watts
*Magnet Wire: #20, 22, 24, 26, 28, 30, 32, 34
Nichrome Wire: Assorted
Parallel Electrical Cording
Plugs
Switches

Glass and Plastic

Acrylic (Plastic) Sheets: 2 cm and 2.5 cm thick
Plates, Glass
Tubes, Glass: 3, 6 mm (1/8", 1/4") internal diameter

Hardware

Bolts and Nuts, Brass or Steel; 3 mm (1/8") diameter: 12, 24, 48 mm (1/2", 1", 2") lengths
Nails: 12, 24 mm (1/2", 1") lengths
Screws, Eye
Screws, Wood: 12, 18, 24, 26 mm (1/2", 3/4", 1", 1 1/2") lengths
Thumbtacks
Washers (Brass and Steel): 6, 9 mm (1/4", 5/16") diameter
Wingnuts (Steel): 5 mm (3/16")

Lumber

Boxwood (Packing Case Material)
Hardboard: 6 mm (1/4") thick
Kiln Dried Wood: 2.5 x 15 cm (1" x 6") cross section
1.2 x 15 cm (1/2" x 6") cross section
Plywood: 6, 12 mm (1/4", 1/2") thickness
Wood Dowels: 6, 12 mm (1/4", 1/2") thickness

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* U. S. Standard Plate numbers are used in this book to indicate the gauge of different wires. Where wires are referenced against other numbering systems appropriate corrections should be made in determining the gauges of materials required. The following comparison of gauges may be of interest:

Standard	Diameter of #20 Wire
Brown & Sharp	0.08118
Birmingham or Stubs	0.089
Washburn & Moen	0.0884
Imperial or British Standard	0.0914
Stubs' Steel	0.409
U. S. Standard Plate	0.09525

Metal Sheets

Aluminum: 0.2, 0.4 mm (1/100", 1/64") thickness.
Brass: 0.4, 0.8 mm (1/64", 1/32") thickness.
Galvanized Iron: 0.4 mm (1/64") thickness.
Lead: 0.1 mm (1/250") thickness.
Spring Steel, Packing Case Bands

Metal Tubes:

Aluminum, Brass, Copper: 6, 12 mm (1/4", 1/2") internal diameter.

Metal Wires

Aluminum: 3 mm (1/8") diameter
Coathanger: 2 mm (1/16") diameter
*Copper: #20, 24
Galvanized Iron: 2 mm (1/16") diameter
*Steel: #20, 26, 30.

Paint Materials

Paint Brushes
Paint Thinner
Varnish
Wood Filler

Miscellaneous

Aluminum Foil
Cardboard Sheeting
Containers (Plastic or Glass)
Corks (Rubber or Cork)
Grease
Hinges: Assorted
Machine Oil
Marbles
Mesh (Cotton, Nylon, Wire)
Modelling Clay (Plasticene)
Paper Clips
Pens: Felt (Marking Pens)
Pins and Needles
Rubber Bands
Soldering Lead
Soldering Paste
Spools
Steel Wool
Straws
String (Cord, Cotton, Nylon)
Styrofoam
Syringes: Assorted
Wax (Paraffin)

*See footnote on previous page.

I. BALANCES

The balances presented have been divided into three categories:

A. ELEMENTARY BALANCES

These are relatively crude, but extremely easy to make, even for elementary students, and serve as an excellent introduction to an understanding of balances.

B. EXPERIMENTAL BALANCES

These are somewhat more exact and are useful for undertaking investigations into the properties of balance.

C. FUNCTIONAL BALANCES

These are relatively sophisticated and designed primarily for functional usage.

A. ELEMENTARY BALANCES

A1. Spring Lever Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	13 cm x 6 cm x 1.5 cm
	1	Wood (B)	5 cm x 2.5 cm x 2.5 cm
(2) Scale	1	Wooden Strip (C)	20 cm x 2 cm x 0.5 cm
	1	White Paper (D)	15 cm x 2 cm
(3) Spring Lever	1	Packing Case Steel Band (E)	30 cm x 1.2 cm x 0.02 cm
(4) Scale Pan	1	Galvanized Iron Wire (F)	50 cm length, #24
	1	Aluminum Sheet (G)	5.5 cm x 5.5 cm x 0.02 cm approximately
(5) Masses	--	Washers (H)	--

b. Construction

(1) Base

Attach wood (B) to one corner of wood (A) to support the spring lever above the base.

(2) Scale

Attach strip (C) vertically to the adjacent corner of the base. Glue a strip of white paper (D) to the top front surface of strip (C) to serve as a scale.

(3) Spring Lever

Take packing case steel band (E) and make a small V-shape at one end to hold the scale pan support wire. Drill two holes in the other end to take two small nails.

Attach the drilled end of band (E) to the top of block (B) on the base with two small nails. Bend the band smoothly over to form an elongated C-shape as indicated.

Steel Band (E)

Strip (C)

Wood (B) Base (A)

(4) Scale Pan

Take the galvanized iron wire (F) and make it into a double strand 25 cm long. Use half of the new length to form a "figure 8" in the wire.

Fold one loop on top of the other, and then bend the remaining straight portion of the wire to the shape indicated. You now have a scale pan support which may be attached to the spring lever.

Pan (G)

Make the pan itself from the aluminum sheet (G). Hammer it at the center to create a saucer shaped pan. Sit the pan on the loop of the scale pan support.

(5) Masses

Such items as nails, washers and paper clips may be used for masses.

c. Notes

(i) Note the point of intersection between the spring lever and the left side of the scale, and record the position with a temporary zero mark. Determine the elastic limit of the spring lever by adding successively larger masses to the scale pan, and noting on each occasion whether the spring returned to the same zero point on removing the masses from the pan. In this particular case it was noted that the elastic limit was reached with a mass of 33 g.

(ii) Note the new zero point on the scale with a permanent mark. This will be slightly below the temporary mark due to the spring being subjected to a force which extended it slightly beyond its elastic limit. Now add masses 1 g at a time calibrating the scale accordingly up to 20 g.

(iii) A more sensitive balance, weighing from 0 to 10 g, may be made in an identical fashion by using half the width of packing case band as the spring lever. Such a balance made here was found to have an elastic limit of 27 g, and was readily calibrated as described above.

A2. Rubber Band Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	15 cm x 10 cm x 1.5 cm
(2) Support	1	Wood Strip (B)	45 cm x 4 cm x 2 cm
	2	Screws (C)	2.5 cm long
	1	White Paper (D)	30 cm x 4 cm
	2	Rubber Bands (E)	--

(3) Scale Pan Unit	1	Nail (F)	7 cm long approximately
	1	Rubber Band (G)	--
	1	Galvanized Wire (H)	#20, 3 cm long
	1	Aluminum Sheet (I)	6 cm x 6 cm x 0.02 cm
	3	Wire (J)	#24, 9 cm long
	1	Adhesive Tape (K)	10 cm x 1 cm
(4) Masses	--	Washers	--

b. Construction

(1) Base

Use wood (A) to serve as the base.

(2) Support

Attach wood strip (B) vertically to the base with two screws (C). Attach the plain white paper (D) to the front of the vertical support (B) with rubber bands (E).

(3) Scale Pan Unit

Drive nail (F) horizontally into top of the vertical support, and suspend a rubber band (G) from its end. Take the galvanized wire (H) and bend it into the shape of a ring which can be suspended from the rubber band.

Hammer the aluminum sheet (I) at its center so as to create a saucer shape, thus producing a reasonable scale pan. Use a hammer and nail to produce three small holes near the perimeter of the pan. Suspend the pan from the ring by means of the three lengths of wire (J) bent over at both ends to form suitable hooks.

To prevent the rubber band sliding backwards and forwards on the supporting nail a length of adhesive tape (K) should be wrapped around the nail so as to leave a groove between the tape and the end of the nail, the rubber band being held in position in the groove.

(4) Masses

Such items as nails, washers and paper clips may be used as masses.

c. Notes

(i) Note the point on the scale corresponding to the position of the unloaded scale pan. Determine the elastic limit of the rubber band by loading the scale pan with increasing masses, noting in each instance whether the unloaded pan returns to the same zero point on the scale. For the particular band used in this instance the elastic limit was reached with a mass of 235 g.

(ii) Check the zero position on the scale once more, making a permanent mark opposite the scale pan, then calibrate the scale by adding successive weights to the pan, keeping well within the elastic limits of the band.

(iii) A nonuniform scale will result.

(iv) The rubber band will deteriorate with time, and this will be particularly rapid in tropical countries. However, the band can easily be replaced and the scale recalibrated so long as the teacher has a suitable set of weights available.

(v) If the scale pan is suspended from two parallel elastic bands, instead of one, the range and the elastic limit will be increased. With two bands the elastic limit increased in this particular case to 550 g. However, it was noted that if masses of less than 500 g were left on the pan for any period of time there was still a tendency for the rubber band to be plastically deformed.

A3. Simple Beam Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Balance Arm	1	Meter Ruler (A)	100 cm long
(2) Pivot	1	Wood (B)	4 cm x 4 cm x 2 cm
(3) Masses	--	Washers (D)	--

b. Construction

(1) Balance Arm

Use the meter ruler (A) as a balance arm.

(2) Pivot

Round off one end of the available piece of wood (B) with sandpaper.

(3) Masses

Use washers or heavy nuts (D) for masses.

B. EXPERIMENTAL BALANCES

B1. Extending Spring Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Rubber Band Balance (A)	I/A2
(2) Spring	1	Steel Wire (B)	0.09 cm diameter, 225 cm long

b. Construction

(1) Support

Make the support (A) in precisely the same way as the rubber band balance described

(2) Spring

under I/A2.

Take a length of steel wire (B) (e.g. piano wire) and fasten one end firmly in a clamp. Attach the other end to a cork borer or similar device (see notes). If the diameter of the axis of the cork borer used is 1.4 cm, the diameter of the resultant spring (when released) will approach 2 cm. Keeping the wire under tension wind some 30 turns of wire into the spring, each turn being separated from the next by about 0.1 cm. Use pliers to twist a loop in each end of the spring. Remove the rubber band which supports the scale pan in the rubber band balance (A), and replace it by the steel spring.

c. Notes

(i) Determine the elastic limit of the steel spring, and calibrate the balance in exactly the same way as for the rubber band balance.

(ii) With the materials described above the spring was extended until the scale pan touched the base of the apparatus without reaching the elastic limit of the spring. The scale was calibrated from 0 to 400 g (an extension of 19.6 cm), and it was noted that the resultant scale was uniform.

(iii) A more sensitive, or weaker, spring may be made by using thinner wire or by making the diameter of the spring greater.

(iv) A very convenient winding device for the spring is a wooden dowel (in this case 1.4 cm diameter, 30 cm long) with a hole (0.6 cm diameter) drilled at either end to take a nail about 10 cm long.

A small hole (diameter 0.2 cm) drilled through the center of

the dowel holds the wire, and the latter may be wound into a spring in much the same way as with the help of the cork borer, in this case winding the wire spring onto the wooden dowel which is turned with the help of the protruding nails.

B2. Compression Spring Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Syringe (A)	Column length approximately 6.4 cm, internal diameter approximately 1.3 cm
	--	Modelling Clay (B)	--
(2) Frame	1	Wood (C)	14 cm x 9 cm x 2 cm
	1	Wood (D)	14 cm x 9 cm x 0.7 cm
	4	Wooden Dowels (E)	12 cm long, 1 cm diameter
(3) Support Block	1	Wood (F)	2 cm x 2 cm x L cm, where L is dependent on length of syringe
(4) Upper Platform	1	Wood (G)	14 cm x 9 cm x 0.07 cm
	2	Bolts (H)	2 cm long, 0.3 cm diameter
	2	Wing Nuts (I)	0.3 cm diameter

(5) Scale Pan	1	Galvanized Wire (J)	32 cm long, 0.4 cm diameter
	1	Aluminum Sheet (K)	12 cm x 12 cm x 0.05 cm
	1	Wood (L)	5 cm x 5 cm x 2 cm

b. Construction

(1) Syringe

Take the disposable plastic syringe (A) and remove the needle and the top flanges. Remove the plunger from the column, and smear the end of the plunger with petroleum jelly thus insuring a well lubricated plunger, and a good airtight seal.

Insert the plunger about 1 cm into the column, and then seal off the open end of the column with modelling clay with the help of the metal needle holder.

(2) Frame

Make the base of the frame from wood (C) drilling holes (1 cm diameter) at the corners to take the dowels (E). Use wood (D) as a platform, drilling holes (1 cm diameter) at each corner to take the dowels. Attach the base and platform together by means of the four dowels, fixing the latter firmly in position with wood cement. Drill a hole (1.4 cm diameter) through the middle of the platform, making it just large enough to take the plunger.

(3) Support Block

Insert the syringe column through the hole in the platform. It will hang suspended with a gap between the bottom of the syringe and the surface of the base. Cut a small support block (F) to fill this gap, and drill a small inset into the top of the block to hold the syringe firmly in position. (The block will also prevent the modelling clay seal in the bottom of the syringe being readily broken under pressure). Fasten the support block to the base with wood cement.

(4) Upper Platform

Make the upper platform from wood (G) to fit on top of the existing platform for the frame.

Drill a hole (diameter the same as that of the syringe plunger) in the middle of the upper platform, and slide the latter into position on the frame. Drill two bolt holes (0.3 cm diameter) through both platforms, and fasten them together by means of bolts (H) and wing nuts (I), thus holding the syringe firmly in position.

(5) Scale Pan

Make a frame for the scale pan out of aluminum or galvanized wire (J).

Cut the corners (2.5 cm x 2.5 cm) out of the aluminum sheet (K), and fold the projections as illustrated so that they may be bent over the wire frame to form a suitable scale pan.

Take the wooden block (L), and drill a hole (the same diameter as the plunger, and 1.5 cm deep) into the middle of the block. Nail the scale pan squarely on to the undrilled surface of the block. Line the inside of the hole in the lower surface with wood filler. Lower the block onto the plunger. The latter will be held firmly within the hole once the wood filler dries.

c. Notes

(i) The balance may readily be calibrated with known weights by noting the length of the trapped air column for each given mass in the scale pan.

(ii) The variation of length of the air column with mass is not linear, as can be seen from the plot below showing the relationship of air column length (L) to the applied mass (M).

M g	L = mm
500	47.8
600	44.8
700	42.4
800	41.2
900	40.0
1000	38.8
1100	37.6
1200	36.4
1500	32.8
2000	28.0

(iii) Because of friction between the plunger and the sides of the column, the syringe tends to be insensitive to weights of less than about 500 g, but it readily measures weights from this lower limit up to around 5,000 g.

(iv) The sensitivity of the balance appears to increase as the length and diameter of the syringe column increases.

(v) In designing new balances it would be of particular interest to consider the use of a syringe as an extension spring, as illustrated in the diagram. It would appear that this balance might have quite a different range and sensitivity from that of the compression spring balance.

B3. Pegboard Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support Stand	1	Wood (A)	50 cm x 10 cm x 2 cm
	1	Pegboard (B)	50 cm x 35 cm x 0.3 cm
(2) Pivot	1	Wood (C)	8 cm x 3 cm x 1 cm
	1	Nail (D)	5 cm long, 0.3 cm diameter
	2	Bolts (E)	2 cm long, 0.3 cm diameter
	2	Wing Nuts (F)	0.3 cm internal diameter
(3) Balance Arm	1	Wood (G)	50 cm x 2.5 cm x 0.5 cm
	1	Aluminum Sheet (H)	2.5 cm x 2.0 cm x 0.02 cm
(4) Hooks	6	Paper Clips (I)	--
(5) Masses	20	Washers (J)	--
(6) Spring Clips	2	Packing Case Steel Bands (K)	8.5 cm x 1 cm x 0.02 cm
	2	Bolts (L)	1.5 cm long, 0.3 cm diameter
	2	Wing Nuts (M)	0.3 cm internal diameter

b. Construction

(1) Support Stand

Attach the sheet of pegboard (B) vertically on to wood (A) to make the support.

(2) Pivot

Drill a small hole (diameter 0.2 cm) through wood (C), and make a small inset over the hole. Drive nail (D) through the hole so that the nail head sits in the inset.

Drill two more holes (diameter 0.3 cm) through the wood, close to the edges, and use bolts (E) and wing nuts (F) to attach the block to the pegboard support stand. The newly attached pivot nail should be at the center of the pegboard and about 20 cm above the base.

(3) Balance Arm

Make the balance arm out of wood (G). Drill holes (0.5 cm diameter) at regular intervals in the arm as illustrated, and balance the arm as required on the nail pivot. Take a sheet of aluminum (H) and bend it into a counterbalance. Set it in an appropriate position on the balance arm to correct any irregularity in the balance of the latter.

(4) Hooks

Make each hook by straightening out a paper clip (I), and cutting off a length of about 6 cm. Then bend the wire into the shape shown. Make six such hooks.

(5) Masses

Use heavy washers (J) or nuts for masses.

(6) Spring Clips

Take a length of packing case steel band (K) and drill a hole (diameter 0.3 cm) through its center. Then bend it as indicated into the form of a spring clip. This size of spring clip is suitable for a standard test tube. Attach this to the support stand with a bolt (L) and wing nut (M). Two identical spring clips should be made.

c. Notes

(i) The position of the pivot in the horizontal lever can be changed at will not only from one end of the lever to the other, but also from the lower edge of the lever to the upper edge (changing the sensitivity of the balance). The apparatus is particularly suitable for studying "moments".

(ii) With the help of the spring clips described the apparatus may be converted into a general support stand.

B4. Soda Straw Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	2	Wood (A)	6 cm x 2 cm x 2 cm
	1	Aluminum Sheet (B)	6 cm x 2 cm x 0.02 cm
(2) Balance Arm	1	Soda Straw (C)	16 cm long approximately
	1	Needle (D)	3 cm long
(3) Masses	10	Paper Clips (E)	--

b. Construction

(1) Support

Screw, or nail, one block of wood (A) on to the other so as to form an inverted sheet (B) and bend this into a three sided support to sit on top of the inverted "T" support. Drill a small hole through the base of the aluminum sheet so that the latter may be attached to the wood support by means of a nail or screw.

(2) Balance Arm

Pierce the middle of the straw (C) with needle (D) making sure that the latter is close

to the top surface of the straw, thus lending stability to the balance arm. Use a razor blade to cut small V-shaped slots in the top surface of the straw at regular intervals of 2 cm. Balance the straw on top of the support.

(3) Masses

Use the paper clips (E) as appropriate masses.

c. Notes

(i) This apparatus is suitable for individual student investigation of the principle of "moments".

B5. Microbalance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	15 cm x 2 cm x 2 cm
	1	Screw (B)	1 cm long
	1	Aluminum Sheet (C)	6 cm x 2 cm x 0.02 cm
(2) Balance Arm	1	Straw	16 cm long approximately
	1	Bolt (E)	1 cm long approximately
	1	Needle (F)	3 cm long
(3) Scale	1	Wood Strip (G)	12 cm x 2 cm x 0.4 cm
	1	White Paper (H)	10 cm x 2 cm
	2	Rubber Bands (I)	--

b. Construction

(1) Support

Bend the aluminum sheet (C) into a three sided support. Drill a hole (0.2 cm diameter) through the middle of the support base, and then attach the support to the end of wood (A) by means of a screw

through the hole.

(2) Balance Arm

Take the straw (D) and select a short bolt (E) which fits tightly into the end of the straw. Screw the bolt partway into the straw. Cut the free end of the straw with a pair of scissors to make an appropriate scale pan in the balance arm. Pierce the straw near to the top surface, and sufficiently close to one end, with the needle (F) so that the latter will serve as a pivot. Balance the straw on the support. A few trials will be necessary to obtain a suitable position for the needle.

(3) Scale

Nail the wood strip (G) vertically on to the end of the base (A), and attach the piece of white paper (H) to the front surface with rubber bands (I).

c. Notes

(i) The position of the pivot and screw should be adjusted so that the straw points toward the top of the scale. Assuming the weight of a large sheet of paper (or several sheets together) can be determined, calibration may be effected by placing a fraction of a sheet of paper (e.g. 1 square cm or less) on the soda straw scale pan, and noting the depression of the straw on the scale. This balance is sufficiently sensitive to determine the mass of extremely small bodies such as mosquitoes, strands of hair etc.

C. FUNCTIONAL BALANCES

C1. Equal Arm Balance ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Softwood (A)	38 cm x 9 cm x 2 cm
	4	Bolts (B)	0.2 cm diameter, 3 cm long
	8	Nuts (C)	0.2 cm internal diameter
(2) Support	1	Screw (D)	3 cm long
	1	Wood (E)	15.5 cm x 3 cm x 2 cm
	1	Razor Blade (F) (Double Edge)	--

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(3) Balance Arm	1	Wood (G)	38 cm x 2 cm x 0.5 cm
	1	Needle (H)	0.1 cm diameter, 5 cm long
	1	Aluminum Sheet (I)	19 cm x 0.5 cm x 0.5 cm
	1	Aluminum Sheet (J)	4 cm x 1.5 cm x 0.05 cm
(4) Scale Pans	2	Aluminum Wires (K)	50 cm long, 0.3 cm diameter
	2	Aluminum Sheets (L)	13.5 cm x 13.5 cm x 0.02 cm
	1	White Paper (M)	4 cm x 2 cm

b. Construction

(1) Base

Base (A)

Side View

Make the base out of softwood (A). Drill four holes (diameter 0.3 cm) in the base to take the four levelling bolts (B). Inset the nuts (C) into the base above and below the holes by hammering the nuts into the wood surface. They may be fixed permanently in position with epoxy resin.

Two nuts (C) on each bolt (B) prevent the latter from wobbling, and permit easy hand adjustment of the bolt.

Bore an additional hole (approximately 0.2 cm diameter) at the center of the base to facilitate the attachment of the support.

(2) Support

Cut the support to the shape shown from a piece of wood (E) and cut slots approximately 1 cm deep in the top surface with a saw. Attach the support to the base with the screw (D) inserted through the hole in the center of the base, making a strong junction with the help of wood cement. Then, cut the

razor blade (F) in half, and, after smearing the cutting edges with epoxy resin, insert the cutting edges of the blades as deep as possible into the slits. The less the blades protrude above the wood the less the strain that is possible on the projecting blades.

(3) Balance Arm

Make the balance arm out of softwood (G), cutting a notch (0.5 cm wide, 1.0 cm deep) at a distance of 1.5 cm from each end of the arm.

Drill a hole (0.1 cm diameter) horizontally through the middle of the arm at a distance of 0.5 cm from the top of the arm. Drive the steel needle (H) through the hole to serve as a pivot, and glue it permanently in position with epoxy resin.

The needle must be sufficiently strong not to bend, even under heavy loads.

Take the sheet of aluminum (I) and bend it into the shape of a pointer as illustrated. Then attach the pointer to the middle of the balance arm.

Complete the balance arm by making a small counterbalance from the sheet of aluminum (J), bending it to the shape indicated. Sit the counterbalance on the balance arm.

(4) Scale Pans

Take the length of aluminum or galvanized wire (K) and bend it into a support for the scale pan. Make an identical support in the same way, and suspend both supports from the notches in the balance arm.

Make the scale pan from the sheet of aluminum (L). Cut squares (3 cm x 3 cm) from the sheet corners to make four projections on the sheet, and cut a slit in one of the projections as indicated. Fold the projections along the dotted lines converting the aluminum sheet into a scale pan with sides. Sit the scale pan on the framework of one of the support wires. Make a second scale pan in an identical manner.

Cross Section

Make a small scale from a piece of white paper (M) by marking regular divisions (0.3 cm apart approximately) on the paper. Glue the scale to the support just behind the pointer so that when the balance arm is perfectly horizontal the pointer will be at the middle of the scale.

c. Notes

(i) The following table gives approximate values for the sensitivity of such a balance under varying loads. Sensitivity is measured as the number of milligrams required to cause the pointer to move one millimeter under the given load.

Load in Each Pan	Sensitivity
25 g	25 mg/mm
50 g	25 mg/mm
100 g	65 mg/mm
250 g	200 mg/mm
500 g	335 mg/mm

(ii) As seen in the illustration, the shape of the razor blade edge allows three different points to be used as fulcrums for the pivot needle. Sensitivity is found to be essentially the same at all three points for all weights.

(iii) The centering point of the pointer is very stable under varying weight loads. However, if the weights are shifted drastically in position in the pans (that is, off center) then shifts in the pointer position of up to 2 mm may be noted.

C2. Box of Masses ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Masses	1-3	Lead (A) (sheeting, etc.)	2 kg approximately
	9	Eye Screws (B)	--
(2) Box	1	Wood (C)	17 cm x 8 cm x 5 cm

b. Construction

(1) Masses

Take a box of wet sand, and use wooden dowels, or some such similar material, to make cylindrical molds in the sand according to the dimensions given below. Heat up some lead (A) in a can, and when it is molten pour it into the molds. Allow the lead to solidify and cool. Then screw into the top of each lead cylinder a cup screw (B) to serve as a handle.

The lead cylinders may then be filed down until each is the desired mass. The number of masses required, and the

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approximate size of each mold, is indicated below.

Qu	Weight	Diameter	Depth
1	500 g	3.8 cm	4.0 cm
3	200	2.4	4.0
1	100	2.4	2.0
1	50	2.4	1.0
2	20	1.2	2.0
1	10	1.2	1.0

(2) Box

Take the block of wood (C) and drill holes, the same size as the above molds, into the top surface. These will serve as suitable mass holders.

C3. Single Pan Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Equal Arm Balance Base (A)	I/C1, Component (1)
(2) Support	1	Equal Arm Balance Support (B)	I/C1, Component (2)
(3) Balance Arm	1	Soft Wood (C)	42 cm x 2 cm x 0.5 cm
	1	Needle (D)	5 cm long
	1	Aluminum Sheet (E)	19 cm x 0.5 cm x 0.05 cm
(4) Scale Pan	1	Equal Arm Balance Scale Pan	I/C1, Component (4)
(5) Counterbalances	--	Washers (F)	Approximately 70 g total
	--	Washers (G)	Approximately 12 g total
	2	Paper Clips (H)	--

b. Construction

(1) Base

Make the base (Component 1) of the Equal Arm Balance (I/C1) and use it as the base (A) of

of this item.

(2) Support

Make the support (Component 2) of the Equal Arm Balance (I/C1) and use it as the support (B) of this item.

(3) Balance Arm

Make the balance arm from the soft wood (C). Drive the needle (D) horizontally through the arm 9 cm from one end and 0.5 cm from the top surface. Cut a notch (0.5 cm wide, 1.0 cm deep) in the top of the arm and drill a small hole (0.2 cm diameter) through the corner of the wood.

Take a sheet of aluminum (E) and bend it into the shape of a pointer as illustrated. Then attach the pointer to the arm just above the pivot.

Sit the balance arm on top of the support so that the needle serves as a pivot.

(3) Scale Pan

Make the scale pan (Component 4) of the Equal Arm Balance (I/C1), and suspend it from the notch in the balance arm.

(4) Counterbalance

If it is desired to use the balance to weigh the masses up to 300 g, a standard 300 g mass should be placed in the scale pan and washers (F) should be suspended from a paper clip (H) to make counterbalance (I).

Side View

The latter should be such that when it is suspended from the end of the balance arm (position Z) it will just balance the 300 g mass. (In this particular instance two washers weighing a total of 70 g were found to be ideal.)

The counterbalance should then be moved to a suitable zero position (Y) on the arm. The balance arm will not remain horizontal. Therefore make a second counterbalance II from the small washers (G) such that when these are suspended from the end of the arm (position X) they will just balance the arm in a horizontal position with counterbalance I in the zero position (Y). (In this instance washers weighing a total of 12 g made a suitable counter-balance II).

You are now ready to calibrate the scale. Stick a piece of paper to the balance arm with adhesive tape to facilitate the marking of the scale. Then place standard masses (50, 100, 150, 200, 250, 300 g) in the scale pan, and in each instance determine the position of the counterbalance (I) which balances the arm. A uniform scale should be created, and this may be subdivided as desired.

c. Notes

(i) Alternative scales may be produced in an identical manner simply by altering the magnitude of counterbalance I (leaving the mass of counterbalance II the same as before). For example using only one washer (35 g) for counterbalance I a scale from 0 to 140 g was created on the same balance.

C4. Spring Balance ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Spring	1	Roll of Steel Wire (A)	#26 gauge (for 10 Newton Balance)
	1	Roll of Steel Wire (B)	#30 gauge (for 1 Newton Balance)
(2) Inner Tube	1	Hollow Aluminum Tube (C)	21 cm long, internal diameter 1 cm
	2	Wood Stoppers (D)	1 cm diameter, 2 cm long
	1	Cup Screw (E)	--
(3) Outer Tube	1	Hollow Aluminum Tube (F)	27 cm long, internal diameter 1.3 cm
	1	Wood Stopper (G)	1.3 cm diameter, 2 cm long
	2	Cup Screws (H)	--

b. Construction

(1) Spring

The most important factor in winding a spring is to keep the wire taut at all times, and for this the help of a

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brace and two nails (10 cm long, 0.7 cm diameter) is invaluable. Drill a horizontal hole about 3 cm deep in the bench for the free moving nail, and about 20 cm to the right of this drive in a second (fixed) nail. Clamp one end of the wire (A/B) along with the head of the free nail in the jaws of the brace, and get your partner to hold the other end of the wire in the jaws of a pair of pliers, keeping the wire taut with the assistance of the fixed nail. Turn the brace, winding the wire firmly around the free nail. The spring may be close wound (each turn touching the next) or open wound (each turn separated from the next by a fixed distance). Although the wire is wound on a nail of diameter 0.7 cm, on release from tension it will tend to expand to about 1 cm diameter.

If a Newton balance is to be made take the #26 gauge steel wire (A) (diameter 0.07 cm) and open wind it (o.1 cm between each turn) into a spring approximately 8 cm long and 0.9 cm in diameter.

Make a loop on one end of the spring (using dog nosed pliers) and a straight piece on the other end.

(2) Inner Tube

Make two stoppers out of the wood (D). Fix a cup screw (E) into one of the stoppers and glue it permanently into one end of the aluminum tube (C). Drill a small central hole through the other stopper (D) and insert the straight end of the spring, bending the end over to hold it in position. Glue the stopper into the other end of the tube.

(3) Outer Tube

Make a wooden stopper (G) to fit one end of the hollow aluminum tube (F). Fix cup screws (H) in either end of the stopper, and attach the top of the spring to one of the cup screws.

Now take the combination of stopper, spring and inner tube, and lower it into the outer tube (F) until the stopper lodges in the top of the tube. Glue the stopper firmly into the tube.

c. Notes

(i) To calibrate the 10 Newton spring, hold the balance vertically, and mark the inner tube opposite the lower end of the external tube (10 Newtons). Suspend 1,020 g from the spring and once again mark the inner tube opposite the lower end of the external tube. Then subdivide the distance between the two marks into 100 equal divisions, thus permitting the balance to read from 0.0 to 10.0 Newtons with an accuracy of 0.1 Newtons.

(ii) To calibrate the 1 Newton spring simply suspend a mass of 102 g from the balance and repeat the above process, calibrating the inner tube from 0.00 to 1.00 Newtons with an accuracy of 0.01 Newtons.

(iii) Spring balances are very easily damaged by over extension of the spring. It is therefore useful to make some simple device to prevent over stressing the spring.

One such method is to tie a piece of magnet wire (diameter 0.05 cm) around the inner cylinder, just above the final marking on the scale. If the lower perimeter of the outer tube is then tapped gently all around it, the magnet wire will be unable to move beyond this point, thus preventing over extension of the spring.

Cross Section

II. TIMING DEVICES

Timing devices have been divided into three groups according to the length of time intervals they would most conveniently measure. This categorization is somewhat arbitrary, and it follows that some devices could, under certain circumstances, exist in more than one category. The categories are defined as follows:

A. LONG INTERVAL TIMERS

The intervals to be measured may range from a day (month, year) down to an hour or minute.

B. MEDIUM INTERVAL TIMERS

The intervals to be measured would range from minutes to seconds.

C. SHORT INTERVAL TIMERS

The intervals to be measured are subdivisions of a second.

A. LONG INTERVAL TIMERS

A1. Sun Dial

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	16 cm x 16 cm x 2 cm
(2) Gnomon	1	Metal Sheet (B)	10 cm x 8 cm x 0.1 cm

b. Construction

(1) Base

Cut the base from the wood (A). Use a felt pen to mark off the surface of the base into four equal portions. Draw a circle (diameter 7 cm) on the base with its center at the middle of the base.

(2) Gnomon

Make the gnomon from the metal sheet (B). Bend the end of the sheet at right angles to the sheet so as to form a base piece 1 cm wide. Drill two screw holes in the base piece. Note the latitude of your locality (e.g., 39° in Washington, D.C.) and mark out a right-angled triangle on the vertical portion of the metal sheet such that the sloping side of the triangle is inclined to its base at an angle equal to the latitude angle. Cut off the sheet above the sloping side. You now have a metal gnomon. Attach the gnomon to the base with screws.

c. Notes

(i) The base of the apparatus should be placed on a horizontal surface with the plane of the gnomon in a true North-South plane, thus making the sloping side of the gnomon parallel to the Earth's axis. Calibrate the sun dial against a clock, marking in the positions of the shadow with a felt pen or paint.

(ii) At the North and South Poles the shadow will move through 15° every hour. Elsewhere the angle rotated per hour will be greater than 15° in the early morning and late evening, and less than 15° towards midday.

(iii) Since the rotation of the Earth is not exactly 24 hours, the sun will not appear to be due North (or South, as the case may be) at noon, Greenwich Mean Time. Each month it will therefore be noted that the sun dial deviates further and further from the conventional time. From 5 to 30 minutes deviation will be noted over a period of one month, depending on the season.

(iv) The apparent motion of the sun may be used in even simpler (but cruder) ways to record the passage of time. It is thus possible to note the motion of a spot of sunlight due to a ray of light passing through a hole in a roof, or due to a ray of light reflected from a mirror placed by a window. The distance moved by the sunspot in successive intervals of time on the same day will be noted to be surprisingly regular. (See sketches on next page.)

Hole
Sunspot
Shadow of
Roof

Mirror
Sunspot

A2. Water Clock

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Upper Reservoir	1	Can (A)	1 liter capacity
(2) Lower Reservoir	1	Can (B)	1 liter capacity
(3) Platform	1	Plywood (C)	50 cm x 15 cm x 1.0 cm
	3	Wood (D)	20 cm x 3 cm x 3 cm
(4) Pointer System	1	Wooden Dowel (E)	8 cm long, 2.5 cm diameter
	1	Wood Strip (F)	35 cm x 0.6 cm x 0.4 cm
	1	Nail (G)	0.2 cm diameter, 4 cm long
	4	Washers (H)	--
	1	Wood (I)	4 cm x 4 cm x 1 cm
	1	String (J)	--
	1	Eye Screw (K)	--

(5) Scale	1	Plywood (L)	40 cm x 30 cm x 0.5 cm
	1	Wood (M)	30 cm x 3 cm x 3 cm
	1	White Paper (N)	30 cm x 40 cm

b. Construction

(1) Upper Reservoir

Take the tin can (A) and drill a small hole (0.1 cm diameter for example) in the middle of the base.

The bigger the can, and the smaller the hole, the greater will be the period of time for which the clock will run. This may be checked now by filling the can with water, and noting the time for it to drain.

If you wish to measure small intervals of time, you may increase the number of holes in the base of the can.

(2) Lower Reservoir

Use can (B) which should be of the same size as, or larger than, the can used for the upper reservoir.

(3) Platform

Take plywood (C) to make the platform, balancing this on the three legs (D) which should be sufficiently long to permit the lower reservoir to be moved under the platform without difficulty. Drill a hole (1 cm diameter) in one end of the platform. Place the upper reservoir over the hole in the platform and the lower reservoir underneath it so that water can run from the upper to lower reservoir.

(4) Pointer System

Make a support from a wooden dowel (E) as indicated. Cut a lower notch in the support to enable it to sit on the side of the upper reservoir (A). Make an upper notch to permit the full movement of the pointer (E) to be attached. Drill a hole (0.2 cm diameter) horizontally through the upper part of the support to permit passage of the nail (G) to serve as the pivot for the lever.

Make the pointer from a strip of wood (F). Drill a small hole (0.3 cm diameter) at one end of the pointer to take the string (J) from the counter-balance, and 8 cm away from this hole drill a second hole (0.3 cm diameter), close to the top surface of the pointer, through which the nail (G) is to be put as a pivot.

Balance the pointer on the newly made support by inserting the nail (G) through the appropriate holes in the support and pointer. Washers (H) should be placed either side of the pointer to serve as spacers. These prevent unwanted motion of the pointer on the pivot. The pivot may be fixed permanently in position in the support with the help of epoxy resin, since the pointer can move about the fixed axle on its own pivot hole.

(5) Scale

Take the small block of wood (I), and attach it to the pointer by means of the string (J) and a screw (K) attached to the top of the block.

Attach a sheet of plywood (L) to the block of wood (M) intended to hold the plywood in a vertical position. Sit the newly made scale on the platform just behind the end of the pointer, sufficiently close to avoid parallax problems in recording the movement of the pointer. Screw the base block (M) of the scale onto the platform. Use a white sheet of paper (N) attached to the surface of the plywood with thumbtacks to actually record a time scale.

Adjust the length of string (J) on the counterbalance so that when the upper reservoir is full of water the pointer will be set towards the bottom edge of the scale.

c. Notes

(i) The counterbalance should be wet all over prior to use so that it does not tend to sink deeper into the water as it is used.

(ii) The water clock may be calibrated against a watch. The scale produced will not be linear since the water pressure over the hole in the base of the upper reservoir decreases as the water level drops. The initial rate of fall of water level is therefore greater than the final rate.

(iii) The clock will be found to be surprisingly reliable, observations being quite repeatable.

(iv) Using an upper reservoir of 1.3 liters, a depth of 19 cm and a base hole 0.15 cm diameter, a five-minute scale was very conveniently created. When the number of holes in the base was doubled the pointer traversed the scale in half the time (2 min 30 sec), and when the number of holes was increased to three the pointer traversed the scale in one third of the original time (i.e., in 1 min 40 sec).

B. MEDIUM INTERVAL TIMERS

B1. Pulse

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pulses	--	--	--

b. Construction

(1) Pulse

Place two fingers from the left hand over the pulse on the right wrist. The pulse beat can easily be detected.

c. Notes

(i) The pulse beat may be calibrated against that of other individuals and against other timing devices. Under normal conditions it remains surprisingly constant, but its rate varies according to the degree of exertion to which the individual is currently subjected.

(ii) It is useful to note that if the pulse in the neck, just below the angle of the jaw, is monitored with one hand, the other hand is left free for other functions.

B2. Simple Pendulum

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) String	1	String (A)	1 meter long
	1	Paper Clip (B)	--
(2) Mass	10	Washers (C)	--
(3) Support	2	Nails (D)	3 cm long

b. Construction

(1) String

Take the length of string (A), and attach a hook [made from the paper clip (B)] to one end.

(2) Mass

Suspend washers (C) from the hook to serve as a variable mass.

(3) Support

Drive two nails (D) into the side of a table, or into a wall, so that the nails are at the same height above the ground. Wrap the desired length of string two or three times around one nail, and fasten the spare length of string to the other nail. This should insure that

the string is pivoted rigidly
at the first nail.

c. Notes

(i) If the length of the pendulum, from the support to the center of gravity of of the mass, is adjusted to 25 cm (or more accurately to 24.8 cm) the pendulum will oscillate with a period of one second.

B3. Classroom Clock *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Pendulum Rod	1	Broom Handle (A)	120 cm long, 2.5 cm diameter
	1	Metal Tube (B)	2.5 cm long, 1 cm external diameter; approximately 0.7 cm internal diameter
	1	Nail (C)	15 cm long, 0.5 cm diameter
(2) Mass	2	Wood (D)	22 cm x 6 cm x 0.5 cm
	2	Wood (E)	30 cm x 6 cm x 0.5 cm
	1	Wood (F)	31 cm x 22 cm x 0.5 cm
	1	Nail (G)	10 cm long, 0.5 cm diameter
	--	Bricks, Rocks, etc. (H)	--

*Adapted from Nuffield Foundation, Guide to Experiments I, Physics, (London: Longmans/Penguin, 1967), pp 79-81.

(3) Support	2	Tables (I)	--
	2	Stools (J)	--

b. Construction

(1) Pendulum Rod

Make the pendulum rod out of the broom handle (A). Drill six holes (0.6 cm diameter) in one end of the rod at 4 cm intervals. Drill another hole (1 cm diameter) 1.5 cm from the other end of the rod. Line this with a short length of metal tubing (B) to reduce friction at the pivot, and insert a long nail (C) through the tube.

(2) Mass

Construct a wooden tray to hold the masses. Use one piece (F) for the base. Nail the four other pieces (D,E) to the base as shown. Drill a hole (2.7 cm diameter) in the middle of the tray base (F), and slide the tray onto the pendulum rod by way of this hole. Insert the strong nail (G) through one of the six holes in the end of the rod to hold the tray in position. The bricks or rocks (H) may be placed in the tray to serve as appropriate masses.

(3) Support

Place two tables (I) fairly close together, and sit the stools (J) on top of both tables, sufficiently close to one another so that the pendulum may be supported by means of its pivot nail resting between the tops of the stools. The nail (G) must be held firmly in position on top of the stools by hand, clamps, or any device which will hold it firmly.

c. Notes

(i) With the length (L) of the pendulum from pivot to tray bottom fixed at 103.5 cm the period (T) of the pendulum was noted to be two seconds.

Mass = 7,000 g

L (cm)	T (sec)
97.0	1.94
101.0	1.98
105.0	2.02
109.0	2.05
113.0	2.09
117.0	2.12

(ii) The initial displacement of the pendulum mass has negligible effect on the period. Keeping the length of the pendulum fixed at 105 cm and the mass constant at 7,000 g the following correlation of period (T) and initial displacement (D) was recorded.

D (cm)	T (sec)
5	1.99
10	2.01
15	2.00
20	2.00

(iii) The period of the swing is virtually unaffected by variation of the mass. Hence, keeping the pendulum length constant at 105 cm, the mass (M) in the pendulum tray was varied by increasing the number of bricks. The following observations of the period (T) were recorded.

M (g)	T (sec)
1500	2.00
3250	2.00
5000	2.00
7000	2.01

(iv) The major effect of increasing the mass (M) of the bricks carried by the pendulum is to reduce the damping effect on the oscillations. With the length of the pendulum fixed at 105 cm, the pendulum mass was displaced a fixed distance (10 cm) and the number of oscillations (N) recorded as the displacement fell from 10 to 5 cm. The following results were obtained.

M (g)	N	Damping Effect
0	51.0	High
1500	95.5	Moderate
3250	97.8	Moderate
5000	98.2	Moderate
7000	131.6	Low

(v) If this timing device is to be used by a large class, it might be useful to modify it slightly to make the counting of oscillations possible without continuous visual observation. It is suggested that a metal container might be attached to the top of the pendulum rod, and a 2.5 cm ball bearing allowed to roll freely in the container, so that a click will occur twice per oscillation as the ball bearing hits the ends of the can.

C. SHORT INTERVAL TIMERS

C1. Ticker Tape Timer ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Vibrator Unit	1	Household Electric Bell (A)	--
(2) Vertical Support	1	Wood (B)	7 cm x 5 cm x 2 cm
(3) Base	1	Wood (C)	16 cm x 6 cm x 2 cm
	2	Screws (D)	3 cm long
(4) Platform	1	Wood (E)	6 cm x 5 cm x 2 cm
	2	Aluminum Sheets (F)	6 cm x 5 cm x 0.05 cm
	1	Carbon Paper (G)	4 cm x 4 cm
	5	Thumbtacks (H)	--

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 12-14.

b. Construction

(1) Vibrator Unit

Take the household electric bell (A), and remove the vibrator unit. (The bell utilized in this instance was designed to operate normally at 10 volts.)

(2) Vertical Support

Use the piece of wood (B) to serve as the vertical support, and attach the vibrator unit to it with screws.

(3) Base

Top View of Base (C)

Use the wood piece (C) as the base. Place the vertical support on the base in such a position that the vibrator arm will be parallel to, and directly above, the line bisecting the length of the base. Mark in the position of the support, and then drill two appropriate holes in the base so as to facilitate the attachment of the support with the screws (D).

(4) **Platform**

Attach the aluminum sidepieces (F) to wood (E) with nails to make a platform. Then with the platform in position on the base, bend the sidepieces at the bottom to hold the platform firmly in contact with the base. (A loosely fitting platform will result in a poor track being recorded on the ticker tape.)

Cut a circular disc out of the carbon paper (G) and pierce the center so that it may pivot freely about a thumbtack (H) in the center of the platform.

Pin four more thumbtacks (H) in the platform to serve as guides for the ticker tape, which must pass under the carbon disc. There must be negligible friction between the guides and ticker tape.

Bend the vibrator arm downwards so that the endpiece is within 0.3 or 0.4 cm of the platform surface.

Side View

c. Notes

(i) Two dry cells in series will generally operate the timer, even though the bell is designed for operation on a 10 volt supply.

(ii) If ticker tape is difficult to obtain, cashiers' paper rolls (for cash registers) are generally available, and may be cut into strips of suitable width, so long as care is taken to obtain smooth straight edges.

(iii) If the ticker tape from the vibrating timer is attached to a moving object, the motion of the object will be recorded on the ticker tape. It is thus possible to determine the distance moved by the object during specific time intervals. This is the basis of a wide range of experiments to determine the relationship between force and motion.

III. CARTS

A. FORCE AND MOTION CARTS

The carts described in this section are presented in increasing order of sophistication, ranging from the simplest cart which can only be used for qualitative observation to the more sophisticated carts which can be used for quantitative experimentation of the relationship between force, mass and acceleration.

A. FORCE AND MOTION CARTS

A1. Elementary Cart *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Cardboard Sheet (A)	15 cm x 14 cm
(2) Wheels	2	Wooden Spools (B)	Diameter of spool ends approximately 4 cm
	2	Coat Hanger Wire (C)	8 cm long, 0.2 cm diameter
	1	Drinking Straw (D)	--
(3) Balloon Support	1	Cardboard Sheet (E)	4 cm x 7 cm
	1	Balloon (F)	--
(4) Spring	1	Packing Case Band (G)	11 cm long, approximately 1.2 cm wide
	1	Washer (H)	Approximately 17 g

*Adapted from Nick Oddo and Edward Carini, Exploring Motion, An Exploring Science Book, (USA: Holt, Rinehart and Winston Inc., 1964), pp 24-27.

b. Construction

(1) Body

Cardboard (A)

Draw dotted lines on the piece of sturdy cardboard (A) and make four slits and four axle holes as illustrated in the diagram. Fold the cardboard along the dotted lines to make a box, fastening the free sides together with the help of adhesive tape.

(2) Wheels

Cross Section

Cut four equal sections (each 1 cm long) from a standard drinking straw (D). Place each section into an axle hole in the body of the cart, and glue firmly in position. The straw sections act as bearings for the axles as well as spacers between the wheels and the body of the cart.

Cut the four wheels from the ends of the two wooden spools (B). Fill the spool holes (0.5 cm diameter) with wood putty and allow the putty to dry hard.

Cut two lengths of wire (C) from wire coat hangers to serve as axles for the cart.

Drill holes, slightly less than 0.2 cm in diameter, through the exact center of each wheel, and put a little epoxy resin in the holes.

Tap the end of one axle into one of these holes, checking carefully to insure that the axle is at right angles (90°) to the wheel, thus avoiding subsequent wheel wobble.

Insert the axle through the body of the cart, and attach a second wheel by the same process. Repeat the procedure with the remaining two wheels and axle, thus providing the cart with front and rear wheels.

(3) Balloon Support

Cardboard (E)

Cut the strong cardboard (E) to a "T" shape as shown. Make a hole (diameter 1 cm) in the center of the top portion. Insert the support through the pair of slits closest to the end of the cart body. Use a rubber balloon (F) to provide acceleration for the cart [see Note (i)].

(4) Spring

Cut the packing case band (G) as indicated to make the spring. To facilitate the throwing of the washers (H) by the spring, bend the top end of the packing case band at an angle. Insert the spring through the remaining slits in the cart.

c. Notes

(i) Spherical balloons, as opposed to sausage-shaped ones, may be held in the balloon support (so long as the spring is removed), and are capable of accelerating the cart by the expulsion of air. The cart will be accelerated most efficiently if the open end of the balloon is held in such a way as to prevent it flopping from side to side with resultant dissipation of energy in all directions.

Not only does the cart motion illustrate action and reaction, but it also demonstrates accelerated motion due to a force. Once the balloon is deflated the acceleration ceases and the cart decelerates to a stop.

(ii) Take a length of strong thread (say 15 cm long), and tie the top end of the spring to the end of the cart in such a way that the top end of the spring is almost horizontal. Place a washer on the top end of the spring. If a burning

match is applied to the thread, the spring will be released and eject the washer forward, while the cart will be propelled backwards, thus offering another demonstration of action and reaction.

A2. Lightweight Cart©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	15 cm x 6 cm x 5 cm
(2) Spring Device	1	Steel Wire (B)	80 cm long, 0.09 cm diameter
	1	Wood Dowel (C)	10 cm long, 1.2 cm diameter
	1	Rubber Stopper (D)	Approximately 2.5 cm diameter, and 1.5 cm long
	1	Screw (E)	1 cm long
(3) Spring Release System	1	Metal Plate (F)	6 cm x 1.5 cm x 0.05 cm

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 39-46.

	2	Screws (G)	1.5 cm long
	1	Wood Dowel (H)	3.5 cm long, 0.8 cm diameter
	1	Steel Wire (I)	#30, 3.5 cm long
(4) Ticker Tape Bracket	1	Aluminum Sheet (J)	15 cm x 1.2 cm x 0.05 cm
	2	Bolts (K)	0.2 cm diameter, 2 cm long
	2	Wing Nuts (L)	0.2 cm internal diameter
(5) Chassis	2	Packing Case Steel Bands (M)	Approximately 15 cm x 1.5 cm x 0.02 cm
(6) Wheel System	2	Wooden Spools (N)	Approximately 4 cm diameter
	2	Coat Hanger Wire (O)	10 cm long, 0.2 cm diameter
	1	Masking Tape (P)	1 cm wide
	--	Washers (Q)	--

b. Construction

(1) Body

Bore a hole from the center of one end of wood (A) to the center of the other end, in order to accommodate a spring device. The diameter of the hole (1.5 cm) should be slightly larger than that of the spring (1.2 cm).

Bore holes into the top surface of the wood (A) to accommodate six masses (see I/C2), namely one 100 g mass (diameter 2.5 cm), four 200 g masses (diameter 2.5 cm) and one 500 g mass (diameter 4.0 cm). The holes should not be so deep as to cut into the horizontal hole for the spring.

(2) Spring Device

Wind about 60 cm of the steel wire (B) into an open spring approximately 8.5 cm long,

1.2 cm in diameter, and with about 0.5 cm separation between each turn. (A method of winding the spring is described under I/C4). Straighten out one end of the spring into a spike and the other to a horizontal loop.

Attach the spring of one end of the wooden rod (C) by means of the spike and epoxy resin. Attach the rubber stopper (D) to the other end of the rod.

Cross Section
(Side view)

Bore a hole into the bottom of the cart body so that it meets the bore hole for the spring 3.5 cm from the end of the body. Then insert the screw (E) to anchor the loop end of the spring.

Ideally, two or three alternative springs of varying thickness and length should be made for trial purposes. The ultimate spring selected will be such that if two identical carts (one carrying three times its own weight) are placed end to end, and the spring device on one cart is then released, both carts will move apart a sufficient distance at uniform velocity to enable a measure of their initial separation velocities to be recorded.

(3) Spring Release System

Fasten the metal plate (F) (brass, steel, etc.) onto the front of the cart with two screws (G) so as to just overlap the top of the hole for the spring.

File a small notch around the wooden rod (C) on the spring device, close to the stopper.

It is thus possible to compress the spring into the hole, and hold it in position by means of the notch and metal plate.

Bore a vertical hole (diameter 0.5 cm) into the top of the cart, near the front end, so that it meets the horizontal bore hole for the spring. The small wooden rod (H) (release rod) inserted into this hole, and pressed against the horizontal rod of the spring device itself, will release the spring from its state of compression. (The need to have the diameter of the spring bore hole slightly

Cross Section

greater than that of the spring and attached rod should now be clear, for it is an essential requirement if the spring is to be released).

Release Rod

Cut the wood dowel (H) to the dimensions illustrated. The rod should be capable of moving freely in its bore hole, but at the same time it should not be so loose that it is easily lost. To prevent losing it, thread a thin piece of steel wire (I) through the rod so that it acts as a spring contact between the sides of the rod and the bore hole.

(4) Ticker Tape Bracket

Sheet Metal (J)

Cut the ticker tape bracket from the sheet of metal (J) (brass, aluminum) which should be reasonably rigid. Make slits (0.1 cm wide) near the end to take the ticker tape, and slots (0.35 cm wide) along the bottom to enable the bracket to be attached to the bolts (K) at the

rear of the cart. Wing nuts (L) should be used to fasten the bracket in position.

Mutual Repulsion

On Inclined Plane

The purpose of the bracket is to insure that ticker tape attached to the cart is in line with the guides of the timer during any experiment, thus reducing friction. Two typical examples are illustrated when carts are mutually repulsed from one another, and when a single cart runs down an inclined plane.

(5) Chassis

Side View

Drill two horizontal holes (0.5 cm in diameter) through the cart body to permit passage of the front and rear axles. Make these holes 1.0 cm from each edge of the cart body (A). Cut the chassis from metal packing case bands (M). Drill five holes along the length of the

strip, two (diameter 0.3 cm) to coincide with the centers of the axle holes and three to enable the strip to be attached firmly to the body with screws.

The axles of the cart will in fact pivot in the chassis holes and not on the wooden holes through the cart, thus reducing friction.

(6) Wheel System

Cut the four wheels from the ends of two wooden spools (N). Fill the spool holes with wood putty and allow the putty to dry hard.

Cut two lengths of wire (O) from wire coat hangers to serve as axles for the cart. Drill holes, slightly less than 0.2 cm in diameter, through the exact center of each wheel, and put a little epoxy resin in the holes.

Cross Section

Tap the end of one axle (O) into one of these holes, checking carefully to insure that the axle is at right angles to the wheel (thus avoiding subsequent wheel wobble).

Insert the axle through the body of the cart, and attach a second wheel by the same process. Repeat the procedure with the remaining two wheels and axle, thus providing the cart with front and rear wheels.

Make small spacers for all four wheels from masking tape (P), in each case wrapping it around the axle (next to the wheel) until it produces a cylindrical spacer 1 cm long and 0.5 cm in diameter.

A little soap applied to each axle will serve as a lubricant between the axle and chassis contact points.

It is convenient to adjust the mass of the completed cart to the nearest 100 g. This may be done by shaving wood off the top or bottom surface of the body of the cart, or by adding washers to the body of the cart. In this case holes were drilled in the bottom of the cart, and washers (Q) fixed in the holes with screws. In this way the mass of the cart was adjusted to 400 g.

c. Notes

(i) This cart will inevitably be affected by friction more than a cart made with ball bearing wheels (III/A3). However, a full range of force and motion experiments may be performed with the cart if an inclined plane is used to compensate for friction affecting the cart. Simply adjust the inclination of the plane prior to any experiment so that the cart runs down the plane with constant velocity, the slope of the plane just compensating for the effect of friction.

A3. Heavyweight Cart

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Body	1	Wood (A)	30 cm x 8 cm x 4 cm
	1	Plywood (B)	30 cm x 8 cm x 0.5 cm
(2) Spring Device	1	Wooden Dowel (C)	16 cm long, 1.2 cm diameter
	1	Roll of Steel Wire (D)	0.09 cm diameter
	1	Rubber Stopper (E)	Approximately 2.5 cm diameter
	1	Screw (F)	4 cm long, 0.2 cm diameter
(3) Spring Release System	1	Aluminum Sheet (G)	8 cm x 3 cm x 0.05 cm
	1	Bolt (H)	3 cm long, 0.3 cm diameter
	2	Nuts (I)	0.3 cm internal diameter
	1	Wooden Strip (J)	8 cm x 2 cm x 0.5 cm
(4) Wheel System	3	Ball Bearing Wheels (K)	Approximately 5 cm diameter
	1	Wooden Dowel (L)	22 cm long, 0.5 cm diameter
	4	Nails (M)	Approximately 2 cm long
(5) Bumpers	2	Wood (N)	12 cm x 2 cm x 2 cm

b. Construction

(1) Body

Cut the body of the cart from the piece of wood (A). Drill horizontal holes (diameter 0.5 cm) close to the front and rear of the cart to hold the axles of the wheel system.

Using a saw and chisel, cut a horizontal slot in the top surface of the cart to contain the spring device, and a vertical slot in the rear of the cart to accommodate the rear wheel.

Use the piece of plywood (B) to make a top plate for the cart, and nail it onto the main body.

(2) Spring Device

Cross Section

Make the spring device according to the instructions given for the previous cart (III/A2), but according to the dimensions indicated here. The spring, made from the steel wire (D), should be 1.2 cm in diameter and 16 cm long (excluding the spike and loop made on the end of the spring). Nail the rubber stopper (E) onto the end of the wooden rod (C), and make a notch (0.2 cm deep) around the rod about 0.5 cm from the end. Place the spring device in the appropriate slot in the cart, and anchor it in position by means of the screw (F) inserted through the top plate of the cart in such a way as to pass through the loop on the end of the spring.

(3) Spring Release System

Cross Section

Bend the sheet of aluminum (G) into an "L" shape (8 cm wide, 2 cm tall, with a base of 1 cm). Attach the sheet to the front of the cart so that the base of the sheet just overlaps the slot for the spring device. In this way the spring may be compressed and held in position by means of the metal sheet and the notch in the rod.

Use the bolt (H) and two appropriate nuts (I) to serve as a releasing device, and bore a hole through the metal sheet and top plate of the cart, 1 cm from the front, so as to expose the rod of the spring device.

The diameter of the hole should be large enough to admit the head of the selected bolt.

Drill a hole through the middle of the wood strip (J). The diameter of the hole should be just large enough to admit the bolt (H), but not the head of the bolt. Place the bolt through the strip with the bolt head beneath the strip, such that it sits in the newly drilled hole in the body of the cart. Nail the strip in position on the front of the cart, and add the two locking nuts (I) to the end of the bolt.

(4) Wheel System

Three ball bearing wheels (K) will have to be purchased (possibly imported) for this

Top View

cart. Cut two axles from the wooden dowel (L). Make the front axle 13 cm, and rear 9 cm long (both 0.5 cm in diameter in this instance). The diameter of the dowel should be the same as the internal diameter of the ball bearing wheels, thus providing a tight fit.

Pass the axles through the axle holes in the cart and fit the wheels appropriately on the axles. Take the four small nails (M), and drill holes of the same diameter as the nails through the axle ends. Insert the nails through the holes, thus securing the axles and wheels in position.

(5) Bumpers

Side View

Use the two strips of wood (N) as bumpers. Nail them in position on top of the cart in such a way that they will hold a second cart (placed on top of the first) firmly in position.

c. Notes

(i) The final weight of the cart will be of the order of 1,000 g. With ball bearing wheels this will not produce too much friction, while it will result in the moving cart having high momentum, and the cart will be little affected by what friction does exist.

(ii) A whole range of experiments related to force and motion will be found in many laboratory books, for example The Physical Science Study Committee, Laboratory Guide, (USA: D. C. Heath and Company, 1965).

IV. WAVE MOTION APPARATUS

A. RIPPLE TANK APPARATUS

There are many ways of introducing wave motion to students, through observations of waves in water, heat radiation, acoustics, optics and electromagnetism. Each approach requires a different set of equipment. The materials here are limited to presenting wave motion through the observation of waves on water, and the equipment is thus limited to ripple tanks and accessories.

A. RIPPLE TANK APPARATUS

A1. Ripple Tank ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basic Tank	2	Wood (A)	60 cm x 3.5 cm x 3.5 cm
	2	Wood (B)	57 cm x 3.5 cm x 3.5 cm
	1	Glass Plate (C)	57 cm x 57 cm x 0.3 cm
	1	Rubber Based Cement (D)	--

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(2) Beach	4	Soft Wood (E)	56.5 cm x 6 cm x 2 cm
	4	Brass Discs (F)	0.05 cm thick, 3 cm diameter
(3) Outlet	1	Metal Tube (G)	5 cm long, 1 cm diameter
	1	Rubber Stopper (H)	2.5 cm diameter, 2.5 cm deep
(4) Legs	4	Wood (I)	60 cm x 3 cm x 2 cm
	4	Bolts (J)	3 cm long, 0.4 cm diameter
	4	Wing Nuts (K)	0.4 cm internal diameter
(5) Lamp Housing	1	Aluminum Sheet (L)	35 cm x 16 cm x 0.05 cm
	1	Plywood (M)	11 cm diameter, 0.4 cm thick
	1	Aluminum Sheet (N)	15 cm diameter, 0.05 cm thick
	1	Lamp (O)	100 watt, straight filament
	1	Electrical Socket (P)	Fits above lamp
(6) Lamp Support	1	Wood (Q)	65 cm x 3 cm x 2 cm
	1	Bolt (R)	4.5 cm long, 0.3 cm diameter
	1	Wing Nut (S)	0.3 cm internal diameter
	1	Wood (T)	48 cm x 2 cm x 1 cm
	1	Triangular Wood (U)	5 cm x 4 cm x 3 cm, and 1 cm thick
	1	Packing Case Steel Band (V)	7 cm x 0.5 cm x 0.02 cm
	2	Aluminum Strips (W)	1.5 cm x 0.6 cm x 0.02 cm
(7) Vibrator Unit	2	Packing Case Steel Bands (X)	30 cm x 1 cm x 0.05 cm
	2	Glass Marbles (Y)	1.5 cm diameter
	2	Wood (Z)	7 cm x 2 cm 2 1 cm
	1	Bolt (AA)	2.5 cm long, 0.4 cm diameter
	1	Wing Nut (BB)	0.4 cm internal diameter

b. Construction

(1) Basic Tank

Out of each of the side wood strips (A and B) cut a single length approximately 2.0 cm x 2.0 cm. (A small circular

saw is useful in performing this task). You now have four large pieces of wood to make the lower frame, and four small pieces to make the upper frame.

The end pieces of the shorter lengths for the lower frame are cut (as illustrated) so that they may be firmly joined together with wood cement.

Set the glass plate (C) on the ledge of the lower frame. Cover the edges of the glass, and the inner edges of the lower and upper frame with a waterproof cement (D) as illustrated. An asphalt or rubber based cement is ideal. Set the glass on the ledge of the lower frame, and hold it in position by placing the upper frame on top of it.

Cross Section of Frame

The whole frame may be held together by clamps, or nails, tacked temporarily through the two frames, until the cement is dry.

Cross Section of Frame

You now have a basic tank with an inner and outer frame insuring the tank is leak proof.

(2) Beach

Plan of Frame and Beach

The beach is any device which will cut out unwanted reflection from the sides of the tank. One of the most effective, and durable of beaches is made from soft pine wood (packing case material). Make the beach rather like a picture frame from the softwood (E) so that it sits on the glass surface of the tank, and fits snugly within the upper frame.

The most important aspect of the beach is the angle of the surface as it slopes downward from its outer to inner edge. The dimensions of a cross section to cope with water depths varying from 0.5 cm to 1.5 cm is illustrated.

Smooth the surface of the beach with fine sandpaper (leaving a smooth, but porous, surface), but do not varnish. Wetting the surface of the beach at the commencement of a series of experiments makes the damping of the waves most effective.

Drill a small hole (0.2 cm diameter) close to the edge of each of the brass discs (F). Attach each to a corner of the frame of the tank with a nail in such a way that the disc may be pivoted about the nail. In this way the discs may be rotated over the beach frame to prevent it from floating, or they may be rotated in the opposite direction to release the beach.

(Beaches may be made from many alternative materials. Fine wire gauze is frequently used for this purpose, but on its own is not as effective as the wooden beach. However, if the surface of the wire gauze is covered with cotton cloth an extremely good beach is created. The only problem is that the cloth must be replaced periodically.)

(3) Outlet

A water outlet is not absolutely essential, but it does make the draining of water from the ripple tank so much simpler, and prevents the spilling of water all over the floor.

Bore a horizontal hole (1 cm diameter) into the ripple tank frame, close to one of the tank's corners, so that drainage

may be assisted by tilting the tank towards the corner. The bottom edge of the outlet hole should be at the same level as the top surface of the glass (or just a little below).

Seal the metal tube (G) into the horizontal hole with a waterproof cement. Bore a hole (0.9 cm diameter) partway into the rubber stopper (H) using an electric drill (not a cork borer). Fit the stopper on the tube, thus controlling the outflow of water.

(4) Legs

Drill and chisel a slot (2 cm x 0.5 cm) in the top of each of the four wood pieces (I) to make adjustment slots for the legs. Make four insets (0.3 cm deep) in the frame to hold the legs firmly in a vertical position. Then, drill a horizontal hole (0.4 cm diameter) through the lower part of the outer frame (that is beneath the level of the glass) at the middle of each inset. Attach each leg to the frame with a bolt (J) passed through the hole in the frame and the slot in the leg. Fasten the bolt and leg firmly in position with a wing nut (K).

(5) Lamp Housing

The size of the lamp housing will be dependent on the size of the contained lamp. In this case the lamp (O) utilized was 8 cm from the socket to

to filament. Ideally the filament should be a straight line, but a slightly bent filament such as that illustrated will serve the same purpose.

To make the housing for the above lamp take a sheet of aluminum (L) and cut an aperture (5 cm x 5 cm) from its center. Roll the sheet into a cylindrical shape, and hold it in position. by means of bent end pieces.

Attach the hardboard or plywood endpiece (M) to the base of the container with very small nails. Drill a central hole in the endpiece to facilitate the placement of the lamp (O) and electrical socket (P). Complete the housing by making a lid out of aluminum sheet (N). Drill a small hole (0.2 cm diameter) in the lid, such that it is in line with the filament.

(6) Lamp Support

The vertical component of the lamp support is made, and attached to the ripple tank, in very much the same way as the legs. Drill and chisel a slot (7 cm x 0.5 cm) near to the bottom of end wood (Q) to permit adjustment. Attach the support to the ripple tank frame with bolt (R) passed through the lower part of the frame, and held in position by wing nut (S).

Cut a rectangular slot (2 cm x 1 cm) in the top of wood (Q) to take the horizontal component, wood (T). Fasten the two firmly together with wood cement. Glue a triangular piece of wood (U) between the two components to make a stronger junction.

In order to attach the lamp housing to the horizontal components of the support make two brackets from steel strips (V) as illustrated. Cut four horizontal slots in the upper part of the lamp housing and

pass the steel strips through. Fasten the loose ends of the brackets together with folded pieces of aluminum (W). Then slide the brackets over the lamp support.

(7) Vibrator Unit

The steel strips (X), or stiff coat hanger wire, will serve as the arms of the vibrator. Attach a glass sphere (Y) to the end of each arm using epoxy resin.

Make the vibrator clamp from two strips of wood (Z). Drill a hole (0.4 cm diameter) through the lower strip, and then attach the strip to the frame with two screws. Set the top strip on top of the first, and fasten it in position with the bolt (AA) and wing nut (BB). The vibrator arms may now be clamped firmly between the strips of the clamp, being held at the middle of the arms. This insures the maximum possible period of vibration.

c. Notes

(i) With the help of the Ripple Tank Accessories (IV/A2) it is possible to observe the phenomena of reflection, refraction, interference and diffraction in waves created in the Ripple Tank.

A2. Ripple Tank Accessories ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Depth Marker	1	Coat Hanger Wire (A)	10 cm long
(2) Straight Line Source	1	Wooden Dowel (B)	40 cm long, 2 cm diameter
	2	Nails (C)	15 cm long approximately
(3) Straight Barriers	1	Wood (D)	40 cm x 2.5 cm x 1 cm
	1	Wood (E)	15 cm x 2.5 cm x 1 cm
	2	Wood (F)	10 cm x 2.5 cm x 1 cm
	1	Wood (G)	5 cm x 2.5 cm x 1 cm
(4) Curved Barrier	1	Hose Pipe with Smooth Surface (H)	55 cm long, 2 cm diameter
(5) Rectangular Plate	2	Glass Sheets (I)	25 cm x 15 cm x 0.4 cm
(6) Curved Glass Plate	2	Glass Sheets (J)	25 cm x 15 cm x 0.4 cm

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 92-95.

(7) Vibrator Mass	1	Iron Bar (K)	11 cm x 2 cm x 0.3 cm
	1	Bolt (L)	0.2 cm diameter, 1 cm long

b. Construction

(1) Depth Marker

Mark off the end of wire (A) in half centimeter intervals (0-2 cm). The marker may then be used to determine the depth of the water at the four corners of the ripple tank, and makes the levelling of the tank simpler.

(2) Straight Line Source

Bore holes into both ends of the wooden dowel (B) and insert long nails (C) into the holes to prevent the rod from floating in the ripple tank.

(3) Straight Barriers

Nail thin strips of lead along the sides and base of the pieces of wood (D, E, F and G) to prevent them from floating in the ripple tank. The weighted pieces serve as suitable barriers.

(4) Curved Barrier

A smooth surfaced hose pipe (H) serves as a suitable curved barrier. The pipe may be curved into any desired arc.

(5) Rectangular Plate

Take a sheet of glass (0.4 cm thick) and mark out two sections (each 25 cm x 15 cm x 0.4 cm) with a glass cutter. Break the glass along the marks by hand. The two newly produced sheets (I) may be set one on top of the other in water, thus

creating a plate of thickness 0.8 cm.

(6) Curved Glass Plate

Scratch guidelines on the glass plates (J) in the shape of a parallelogram. Cut along the lines with a glass cutter, and break the glass along the lines. Grind down the shape to a curve, as indicated, with the help of a sandstone. The two plates may be used one on top of the other in the ripple tank, making a plate of thickness 0.8 cm.

(7) Vibrator Mass

The soft iron bar (K) should weigh approximately 50 g. Place the bar in a strong clamp, and use a hammer to bend it in half so that it becomes two parallel bars about 0.3 cm apart. Drill a hole (0.2 cm diameter) in the middle of the top bar, and make a thread (0.2 cm diameter) in the hole. Screw bolt (L) into the hole thus making it possible to clamp the bar onto the ripple tank's vibrator arm.

A3. Stroboscope ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Wheel	1	Hardboard (A)	25 cm diameter, 0.3 cm thick
(2) Handle	1	Wooden Dowel (B)	25 cm long, 2 cm diameter
(3) Pivot	1	Bolt (C)	4.5 cm long, 0.4 cm diameter
	1	Wing Nut (D)	0.4 cm internal diameter
	1	Nut (E)	0.4 cm internal diameter
	1	Wood (F)	3 cm diameter, 1.5 cm thick

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 96-97.

(1) Wheel

Cut the stroboscope wheel from the piece of hardboard (A). Make 12 equally spaced slits in the perimeter of the wheel. Drill a finger hole (2 cm diameter) at a distance of 3 cm from the center of the wheel, and a pivot hole (0.5 cm diameter) at the center of the wheel.

(2) Handle

The handle is simply a wooden dowel (B). Drill a hole (0.4 cm diameter) through one end of the nandle to take the pivot bolt (C).

(3) Pivot

Detail
(Cross-section)

Use the bolt (C) to serve as the pivot for the wheel. Insert this through the wheel, the spacer (F), a locking nut (E) and the handle (B). Use the locking nut (E) and the wing nut (D) to hold the handle in a fixed position on the pivot.

c. Notes

(i) If the components of a moving body repeatedly take up fixed positions at regular intervals (e.g., vibrating bodies, waves) it is possible to "stop" the motion by viewing it through the slits of the stroboscope, rotated at an appropriate speed.

V. THE MULTIPURPOSE SYRINGE

The purpose of this chapter is to illustrate some of the multiple uses to which a syringe may be applied. The syringe devices are therefore grouped according to the concepts they are intended to illustrate.

A. AIR PRESSURE APPARATUS

The devices in this section are all concerned with varying air pressure in the syringe.

B. SPECIFIC GRAVITY APPARATUS

The syringes in this section are used in one way or another to determine the specific gravity of solids and liquids.

A. AIR PRESSURE APPARATUS

A1. Hydraulic Press

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	2	Wood (A)	20 cm x 5 cm x 2 cm
	2	Wood (B)	17 cm x 5 cm x 2 cm
(2) Syringe Assembly	1	Plastic Disposable Syringe (C)	10 cc capacity
	1	Plastic Disposable Syringe (D)	60 cc capacity
	1	Rubber Tube (E)	20 cm long, 0.5 cm diameter
	2	Fine Wire (F)	5 cm long

b. Construction

(1) Support

Nail the two shorter pieces of wood (B) to the ends of one of the longer pieces (A) in upright positions. Before

nailing the last piece (A) into position across the top of the support, two holes must be drilled in it. These holes must be slightly larger in diameter than the barrels of the syringes used. Make these holes about 10 cm apart.

(2) Syringe Assembly

Attach one end of the rubber tube (E) to the nozzle of the larger syringe (D). Wrap one piece of wire (F) around this joint to seal it as tightly as possible. Withdraw the plunger of this syringe halfway to fill it with water through the end of the rubber tube. Try to eliminate as many of the air bubbles from the syringe as possible.

Holding the free end of the rubber tube so that no water can escape, run the end of the tubing through the hole in the support and put the large syringe into position. Put the barrel only of the small syringe (C) into position, and connect the end of the rubber tubing to the

nozzle. Again, use the wire (F) to make the junction tight. Push the plunger of the large syringe down until the water rises in the small syringe and is about to run over. Insert the plunger of the small syringe now and push down, and a minimum of a air should be trapped in the system.

c. Notes

(i) The lifting power of the hydraulic press may be felt by exerting a gentle downward pressure on each syringe simultaneously with both hands. The load on the smaller syringe will lift the plunger of the larger syringe, even when the load on the latter is felt to be greater than that on the smaller syringe.

A2. Vacuum Apparatus

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Fixed Syringes	1	Plastic Disposable Syringe (A)	35 cc capacity
	1	Plastic Disposable Syringe (B)	10 cc capacity
	2	Nails (C)	4 cm long
(2) Clamp and Tube	1	Plastic Tube (D)	20 cm long, 0.5 cm diameter
	1	Screw Clamp (E)	CHEM/IV/A5

b. Construction

(1) Fixed Syringes

Use a drill of a slightly larger diameter than that of the nails (C) to carefully make holes through the barrel and plunger of the plastic syringe (A). When the nail (C) is inserted through these holes, the plunger should be held in a position such that the volume in the syringe is 25 cc. Similarly, prepare the second syringe (B) so that the volume is held at 5 cc capacity when the nail is in place.

(2) Clamp and Tube

Connect the two syringes with the length of plastic tube (D). Be certain the connections between the nozzles and tubing are tight. Also, the tubing must be flexible enough to allow the clamp to close it off completely while, at the same time, it should be elastic enough not to collapse as pressure in the system becomes lower. The clamp (E) will close off air flow through the tube most easily when the tube is doubled over against itself.

c. Notes

(i) To use this piece of equipment to create a vacuum in the larger syringe (A), first fix the volume of the air in the syringe (A) at 25 cc using the nail to hold the plunger in position. Connect the clamp and tubing to it. Depress the plunger in the smaller syringe (B) completely, then fasten the syringe to the tubing, and close the clamp. Now, open the clamp and withdraw the plunger in the smaller syringe. This will extract air from the larger syringe. Fix the plunger of the smaller syringe with the nail, and reclose the clamp. Remove the smaller syringe from the tubing.

The extraction procedure may be repeated five or six times in succession in order to produce very low pressures.

(ii) After one or more extractions, the reduced pressure in the large syringe may be determined by holding the syringe under water and removing the clamp from the tube. Water will rise in the syringe until the trapped air is once again at atmospheric pressure. Note the volume of the trapped air.

If

The volume of air finally trapped above water = V_2
The pressure of air finally trapped above water = P_2
(Where P_2 = atmospheric pressure)

And if

The volume of same mass of air prior to contraction = V_1
(Where V_1 = volume of syringe)
The pressure of same mass of air prior to contraction = P_1

Then

The pressure of the vacuum created is given by

$$P_1 = \frac{P_2V_2}{V_1}$$

(iii) In a typical experiment (results indicated below) five extractions reduced the pressure in the large syringe to 0.5 atmosphere pressure.

No. of Extractions	V_2 cc	V_1 cc	P_1 Atmospheres
1	25	23	0.92
2	25	19.5	0.78
3	25	16.5	0.66
4	25	14.5	0.58
5	25	12.0	0.48
6	25	10.5	0.42

A3. Elasticity Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Size can be variable

b. Construction

(1) Syringe

Place a finger over the air outlet to seal the air in the tube.

c. Notes

(i) With a sealed syringe, elasticity of air may be felt by pushing down or pulling out the plunger. In either case, if the syringe is airtight, the plunger will be pusned or pulled back to its original position by the air trapped in the syringe.

(ii) It is of interest to replace the air in the syringe by water in order to compare the elasticity of water with that of air.

A4. Gas Expansion Device ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe Unit	1	Plastic Disposable Syringe (A)	Size can be variable
	2	Beakers (B)	Approximately 250 ml

b. Construction

(1) Syringe Unit

Any size syringe (A) may be used, but one approximately 10 - 15 cc in capacity is convenient. Fill one beaker (B) with hot water and the other with cold water.

c. Notes

(i) After the syringe has been filled with suitable gas (e.g., air) it is placed in the cold water bath for several minutes. It is then removed, emptied of any water which may have entered through the open nozzle, adjusted to a volume of 5 or 10 cc, and placed in the hot water bath. As the gas expands, bubbles will leave the syringe. After the bubbling has ceased, remove the syringe and place

© From Andrew Farmer, "The Disposable Syringe: Additional Experiments," School Science Review, CLXXVIII (1970), pp 59-60.

it back in the cold water bath. As the gas contracts, water will enter the syringe, and the amount of water entering serves as a measure of the expansion of the gas. Quantitative data on gas expansion can be obtained by using the same gas and syringe, and varying the temperature of the hot water bath, or by using the same syringe and hot water bath and varying the gases.

B. SPECIFIC GRAVITY APPARATUS

B1. Volume Determinator

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	Size can be variable
	1	Beaker (B)	Approximately 250 ml

b. Construction

(1) Syringe

Choose a plastic, disposable syringe (A) with a barrel capacity large enough to hold the object whose volume is to be measured. Fill the beaker (B) about one half full of water.

c. Notes

(i) Use this apparatus by placing the object whose volume is to be measured into the syringe. Replace the plunger and depress it until it almost touches the object in the bottom of the syringe. Hold the syringe so that the end of it is under water in the beaker. Draw enough water into the syringe to cover the object by withdrawing the syringe plunger. Find the difference between the

original syringe reading and the final syringe reading. This indicates the volume of water drawn into the syringe. Note the apparent volume of water in the syringe (that is the volume of the object and the water combined) and subtract from this the volume of water known to have been drawn into the syringe. The resultant value indicates the volume of the object.

B2. Specific Gravity Device

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Syringe	1	Plastic Disposable Syringe (A)	35 cc capacity

b. Construction

(1) Syringe

Use the syringe (A) with no modification except to remove the needle, as usual.

c. Notes

(i) To determine the specific gravity of a liquid, simply draw up 25 cc of the liquid, and find the mass of the liquid plus syringe. Subtract the mass of the empty syringe from this total to find the mass of the liquid. Divide the mass of the liquid by 25 to obtain the specific gravity.

(ii) If the liquid should leak from the syringe, simply seal the nozzle of the syringe with a nail. Remember to add the mass of the nail into the calculations.

B3. Hydrometer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Weighted Syringe	1	Plastic Syringe Barrel (A)	35 cc capacity
	6-8	Metal Washers (B)	Slightly less wide than the barrel

b. Construction

(1) Weighted Syringe

Place enough washers (B) in the syringe barrel (A) to cause it to sink to the 25 cc mark when placed in water. Seal the nozzle by heating it until it melts shut.

c. Notes

(i) For use as a hydrometer, the syringe barrel must be calibrated. Use a graduated cylinder (CHEM/III/B2) to make the calibrations. Note the water volume in the cylinder before and after the syringe barrel is placed in it. The difference of these two values indicates the volume of water displaced by the syringe. By this means it is possible to indicate a displacement value for each reading on the syringe. The following table was created for the syringe under test.

Scale on Syringe	Volume of Water Displacement
cc	cc
20	27.2
21	28.6
22	29.2
23	30.4
24	31.5
25	33.0
26	34.5
27	36.1
28	37.5
29	38.4
30	39.6

Weigh the syringe (and its washers), and then place it in the liquid whose density is to be determined.

(ii)

If

V = The volume of liquid observed to be displaced

M - The mass of the syringe and washers

Then

M = The mass of liquid displaced

$M/_V$ = The density of the liquid displaced

VI. OPTICS APPARATUS

The apparatus in this section has been grouped according to the concepts, and are identified as follows:

A. GENERAL APPARATUS

This apparatus is for use in studying all aspects of optics whether this might be reflection and refraction, or interference and diffraction.

B. REFLECTION APPARATUS

This apparatus is sufficient for a simple study of reflection. The electroplated mirrors are preferable to brass mirrors described, although the latter will be found adequate for most purposes.

C. REFRACTION APPARATUS

Apparatus for the study of refraction using plastic prisms.

D. LENS APPARATUS

Apparatus to enable a study of the properties of lenses.

E. DIFFRACTION AND INTERFERENCE APPARATUS

A study of the basic phenomena of interference and diffraction is possible with this apparatus, using simple slits, holes and thin films.

A. GENERAL APPARATUS

A1. Light Source©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Lamp Housing	1	Ripple Tank, Lamp Housing (A)	IV/A1, Component (5)
(2) Base	1	Plywood (B)	21 cm x 11 cm x 0.5 cm
	2	Wood Strips (C)	16 cm x 2.5 cm x 1 cm
	2	Wood Strips (D)	11 cm x 2.5 cm x 1 cm

b. Construction

(1) Lamp Housing

This lamp housing (A) is precisely the same as that designed for the ripple tank (IV/A1). All that is added is a base.

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(2) Base

Make the base from the piece of plywood (B). Nail the two short pieces of wood (D) to the ends of the plywood (B) and nail the remaining wood strips (C) to the plywood, too. Make sure that they will hold the lamp housing firmly in position. Then nail it into position.

c. Notes

(i) This light source may be used in conjunction with the Slit/Aperture Combination (VI/A2) to investigate the behavior of rays of light transmitted from the source. The light source is designed for use with all the items included in this chapter, including the interference and diffraction apparatus. If the bulb used is bright (e.g., 100 watts), there will be no need to black out the laboratory.

A2. Slit/Aperture Combination

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Metal Sheet	1	Aluminum Sheet (A)	15 cm x 10 cm x 0.02 cm
(2) Framework	4	Wood Side Strips (B)	15 cm x 1 cm x 0.5 cm
	2	Wood Side Strips (C)	15 cm x 2 cm x 0.5 cm
	2	Wood Strips (D)	11 cm x 2 cm x 0.5 cm

b. Constr.ction

(1) Metal Sheet

Cut the slit (0.1 cm width) and apertures (0.1 cm diameter) in any suitable thin sheeting (A) (metal, bakelite, cardboard) so long as the slit and apertures have clean cut edges. If the material used is relatively rigid, a small wooden block will provide adequate support. If the material tends to flex under its own weight, a framework, such as that indicated below, will be required for support.

(2) Framework

Nail or glue two wood strips (B) to a third strip (C), leaving about a 0.1 cm gap between them. Make an identical piece from the other two narrow strips (B) and the one remaining wide strip (C). Slide the metal sheet into position between the two pieces.

Nail the top and bottom pieces (D) to the two upright pieces to complete the framework. The thickness of the bottom strip (D) should not be much more than 0.5 cm, as there is a tendency for this strip to cut off a desirable portion of any light path.

c. Notes

(i) The decision as to whether to use a frame will probably be one of economics. Thick metal sheets are much more expensive than thin ones, but the cost of labor involved in making a framework for a thin sheet may in some instances offset the difference between the two.

(ii) The slit is primarily intended for delineating light rays (from the Light Source, VI/A) which may be traced across a horizontal surface.

(iii) If the metal sheet is placed on its side the apertures will sit at an appropriate height in front of the Light Source (VI/A1), and may be used as objects for experiments with lenses.

B. REFLECTION APPARATUS

B1. Mirrors and Electroplating ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Mirror	2	Brass Sheet (A)	10 cm x 2.5 cm x 0.1 cm
(2) Holder	2	Metal Strapping (B)	Approximately 6 cm x 2 cm x 0.02 cm
	2	Plastic Tape (C)	2 cm x 1 cm

b. Construction

(1) Mirror

Cut the sheet of brass (A) on a metal guillotine (to be found in your nearest metalwork shop). If the metal sheet is cut with bench sheers some distortion is almost certain to result, thus lowering the quality of the mirror. If the mirror is to be curved, bend it over a smooth, curved, wooden block until the mirror becomes the arc of a circle of radius 8.5 cm.

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Polish the metal strips first with coarse carborundum paper, and then with successively finer and finer grades, taking care at each polishing to remove the deeper marks of the previous polishing.

Obtain a mirror finish by polishing the surface with a soft cloth and metal polish.

(2) Holder

Bend the piece of metal packing case band (B) into a triangular shape. Curve the endpieces and cover them with the plastic tape (C) to protect the mirror surface.

Alternatively, cut a slot (0.2 cm wide) in a wooden block (2 cm x 2 cm x 2 cm). Line the slot with plastic tape to prevent the wood from scratching the surface of the mirror to be held.

c. Notes

(i) Brass mirrors must be cleaned with metal polish before each usage. This process may be eliminated if the metal surface is electroplated. The procedure to be followed is described below:

Procure a plastic, or glass, container about 15 cm deep and 10 cm in diameter, and fill it with a nickel solution (e.g., Gleamax and Levelbrite).

Wash the polished brass mirror in caustic soda (soap) to remove grease and rinse with clean water. Grip the brass mirror in a crocodile clip, attached to an electrical lead, and suspend the brass mirror in the nickel solution. The

mirror may be held in position by wrapping the electrical lead (by which it is suspended) around a wooden dowel bridging the container.

Suspend a nickel plate in a similar fashion from a second electrical lead. We now have an anode (nickel plate), a cathode (brass mirror) and an electrolyte (nickel solution).

Connect the anode to the positive terminal and the cathode to the negative terminal of a 6 volt battery, and pass a current through the nickel solution for 15 to 20 minutes. The quality of the final surface will depend primarily on the quality of the initial polished surface, prior to electroplating.

(ii) Mirrors may also be made by a very simple chemical process. Prepare three solutions as follows:

I.			II.			III.		
	40 ml	H_2O		10 g	NaOH		100 ml	Concentrated fructose solution (Glucose or any aldehyde may be used, although the reaction may be slower).
	60 ml	Concentrated NH_4OH		100 ml	H_2O			
	10 g	$AgNO_3$						

Just before using, mix equal volumes of solutions I and II. Then add the fructose solution to the new mixture in the ratio of 1:4. Silver will deposit on any glass surface in contact with the solution. If a microscope slide is placed in the solution, it will be coated on two sides. The external appearance will be dullish. Remove one such coating with a cloth. The glass-silver interface will be seen as an excellent mirror.

B2. Optical Board and Accessories

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Optical Board	1	Hardboard (A)	40 cm x 40 cm x 0.5 cm
(2) Steel Pins	2	Steel Rods (B)	7 cm long, 0.1 cm diameter
(3) Steel Pins with Sleeves	2	Steel Rods (C)	7 cm long, 0.1 cm diameter
	2	Pencils (D)	6.5 cm long
(4) Protractor	1	Aluminum Sheet (E)	10 cm x 5 cm x 0.05 cm

b. Construction

(1) Optical Board

This is simply a piece of hardboard (A) into which pins can be readily stuck. Normally a plain sheet of paper will be placed on top of the hardboard to facilitate the recording of experimental observations. The Refraction Model Apparatus (VI/C3) is such a piece of hardboard.

(2) Steel Pins

The steel rods (B and C) may be cut from cycle spokes or similar steel rods. Sharpen one end of each rod with the help of a file.

(3) Steel Pins with Sleeves

Remove the pencil lead from the pencils (D) with the help of a steel pin. Coat the steel pin (C) with epoxy resin, and slide it into the space originally occupied by the lead, so that, instead of the pencil lead, a steel pin protrudes from the end. Cover the sleeve with a white coat of paint.

(4) Protractor

Make a protractor by cutting a semicircular piece of metal from the aluminum sheet (E). Mark as many angles around the periphery of the protractor as desired.

C. REFRACTION APPARATUS

C1. Optical Prisms and Lenses ©

(1) Prisms

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Prisms	1	Sheet of Acrylic (A)	16 cm x 10 cm x 2 cm

b. Construction

(1) Prisms

Triangular Prism

Take the sheet of acrylic (A) and mark out the shape of the desired prism with a sharp point. Draw a parallel set of lines about 0.5 cm outside the initial marking. The inner markings should outline a triangle (3 cm x 3 cm x 3 cm), a rectangle (8 cm x 5 cm) and a semicircle (9 cm diameter).

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Rectangular Prism

Using a fine-toothed saw, carefully cut the plastic down to the outer markings. The cut produced will have very jagged edges, the plastic showing a tendency to chip. This is normal, and should cause no concern.

Semicircular Prism

The next step is to remove the rough edges from the prism, reducing its size to that of the inner markings. For this purpose place a coarse sheet of carborundum paper on top of a smooth surface (e.g., a strong glass sheet). Then smooth down the surfaces of the prism by rubbing them on the carborundum surface.

Repeat the process with successively finer and finer grades of carborundum paper, taking care at each rubbing to remove the deeper marks of the previous rubbing.

Finally, replace the carborundum paper by a sheet of plain paper. Drop a little metal polish on the paper, and repeat the rubbing process. The surface produced will be highly polished.

The rubbing and polishing process is repeated with all the surfaces except that surface which will normally be in contact with the table top during experimentation. This surface is smoothed with carborundum paper, but not metal polish, thus leaving the surface sufficiently rough to scatter light.

c. Notes

(i) Plastic is not as hard as glass, and is therefore more easily scratched and damaged. From time to time it is therefore necessary to repolish the surfaces with metal polish, as described above.

C2. Screen with Holder

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Screen	1	Cardboard (A)	25 cm x 15 cm
	1	White Paper (B)	25 cm x 15 cm
	1	Black Paper (C)	25 cm x 15 cm
(2) Holder	1	Wood Block (D)	4 cm x 4 cm x 4 cm
	1	Steel Band (E)	Approximately 8 cm x 1 cm x 0.02 cm

b. Construction

(1) Screen

Make the screen from the stiff piece of cardboard (A). It is very convenient to have a front white surface and a rear black surface. This may be achieved by sticking appropriate sheets of paper (B,C) on the two surfaces.

(2) Holder

Bend a length of packing case steel (E) as shown and nail it to the side of the wooden block (D).

c. Notes

(i) The white surface of the screen is used for normal image formation, while the black surface is useful whenever the screen is used as a barrier to exclude light.

C3. Refraction Model Apparatus

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Platform	1	Hardboard (A)	40 cm x 40 cm x 0.5 cm
	2	Hinges (B)	Approximately 2 cm long, sidepieces no more than 0.5 cm wide
(2) Supports	2	Wood (C)	30 cm x 4 cm x 2 cm
(3) Ramps	1	Wood (D)	12 cm x 5 cm x 2 cm
	1	Wood (E)	12 cm x 3 cm x 2 cm
(4) Ball Bearing	1	Ball Bearing (F)	2.5 cm diameter

b. Construction

(1) Platform

Hardboard (A)

Cut a 7 cm strip from one side of the plywood (A), and shape the newly cut edges back at an angle of 45° as illustrated. Reattach the 7 cm strip to the platform with very small hinges (B) avoiding the creation of a gap between the strip and main platform. Shape the free edge of the 7 cm strip to an angle of 45°. This shaping insures good contact between the strip and the table.

(Also see illustration on next page.)

(2) Supports

Books, or blocks of wood (C), may be used to elevate the platform to different heights above the table top (e.g., 2 and 4 cm).

(3) Ramp

Cut two triangular shapes out of the pieces of wood (D,E). The height (h) of one triangular shape will be 5 cm and the other will be 3 cm, while both will have a base 12 cm long.

The groove is best cut with the help of a saw.

c. Notes

(i) This apparatus is used to demonstrate the refraction of light according to Newton's Corpuscular Theory. The ball bearing may be rolled down the small ramp, across the top platform and down the ramp, or alternatively down the large ramp, across the table top and up the ramp. In either case refraction occurs in crossing the ramp from one level (or medium) to another, and appropriate comparisons may be made with the transmission of light across a boundary (ramp) from one medium (level) to another.

C4. Filter

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cellophane	1	Red Cellophane (A)	10 cm x 3 cm
(2) Frame	2	Cardboard (B)	10 cm x 3 cm

b. Construction

(1) Cellophane

Test different strips of red cellophane (A) for suitability by noting what parts of a spectrum can be seen through the cellophane. The cellophane cutting out almost all colors other than red will be most suitable.

(2) Frame

Cut the two pieces of cardboard (B) to the shape indicated, and stick (or clip) a suitable piece of red cellophane (A) between the two pieces.

c. Notes

(i) Filters are very useful not only in studying the way in which different colors of light superimpose one on the other, but also for the creation of monochromatic light. This is particularly important in studying interference and diffraction phenomena.

D. LENS APPARATUS

D1. Lens with Holder ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	10 cm x 5 cm x 1 cm
(2) Uprights	2	Wood Strips (B)	12 cm x 2 cm x 1 cm
	2	Screws (C)	1.5 cm long
(3) Top Plate	1	Metal Sheet (D)	7 cm x 1 cm x 0.1 cm
	2	Screws (E)	Approximately 0.7 cm long
(4) Lens	1	Magnifying Glass (F)	--

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b. Construction

(1) Base

Make two insets (0.5 cm deep) in the wood (A) to take the two uprights (B). Drill a small hole (0.2 cm diameter) in the middle of each inset.

(2) Uprights

Set the uprights (B) in the base insets with wood cement, insuring a firm joint by screwing the very small screws (C) through the base into the upright.

(3) Top Plate

Cut the top plate out of aluminum or brass (D). Drill a small hole (0.2 cm diameter) at a distance of 1 cm from each end. Attach the top plate to the uprights with very small screws (E).

(4) Lens

Purchase a suitable magnifying glass (F) locally. It may be held in any position on the upright by means of rubber bands.

D2. Multiple Slits

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Framework	2	Wood Strips (A)	10 cm x 2 cm x 0.5 cm
	2	Wood Strips (B)	4 cm x 2 cm x 0.5 cm
(2) Nails	1	Box of Nails (C)	0.2 cm diameter, more than 4 cm long

b. Construction

(1) Framework

Make regular indentations down the middle of the top and bottom strips (A) of the framework, the indentations being 0.4 cm apart. These indentations can easily be made with a hammer and nail. The remaining two pieces of wood (B) will serve as sidepieces for the framework. Do not complete construction of the framework until the nails (C) are in place.

(2) Nails

Take a handful of nails (C) and cut off the top ends to produce a uniform set of nails, each 4 cm long. Tap the nails into the bottom strip (A), positioning them in the indentations. Then press the upper strip (A) onto the upright nails, using the indentations on the upper strip for guidance in positioning the nails parallel to one another. Finally, attach the sidepieces (B) of the framework using very small nails or wood cement.

c. Notes

(i) The multiple slits are used primarily to break up beams of light into multiple pencils of light. Many alternative devices could be used for the same purpose, e.g., a hair comb supported by a wooden block.

E. DIFFRACTION AND INTERFERENCE APPARATUS

E1. Fixed Single and Double Slits

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Fixed Slits	1	Exposed Film (A)	Approximately 5 cm x 3.5 cm

b. Construction

(1) Fixed Slits

Take an exposed strip of film (A) (or a slide coated with colloidal graphite) and draw a straight line across it using a razor and a straight edge as a marker. The width of the slit may be increased, if desired, by drawing the razor over the same approximate line two or three times. Do not cut through the film.

A double slit may be made in an almost identical way. Simply hold two razors face to face, and draw the line across the film with the two razor blades pressed closely together. The space between the slits may be increased, if desired, by holding the blades at an angle to the vertical as the double line is drawn against the straight edge.

c. Notes

(i) In making single or double slits it is well worthwhile repeating the procedure several times on different parts of the film, and then selecting the best slits after testing.

(ii) If the slits are held in a vertical position close to the eye, and if the vertical filament of the Light Source (VI/A1) at a distance of about three meters is viewed through the slits, interference and diffraction patterns will be observed even in daylight. The patterns are clarified by the use of the Filter (VI/C4) placed in front of the slits.

E2. Adjustable Single Slit

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Adjustable Slit	2	Razor Blades (A)	--
	1	Metal Strip (B)	Approximately 7 cm x 2 cm

b. Construction

(1) Adjustable Slit

Hold the two razor blades (A) against the metal strip (B) so that the edges of the blades are almost touching and are parallel to one another.

c. Notes

(i) If the slit is held in a vertical position close to the eye, and the vertical filament of the Light Source (VI/A1) viewed at a distance of about three meters, a diffraction pattern may be observed in daylight conditions. The pattern is clarified by the use of the Filter (VI/C4) placed in front of the slit. The effect on the pattern of changing the slit width may readily be observed.

E3. Diffraction Holes

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Metal Strip	1	Metal Strip (A)	10 cm x 2.5 cm x 0.1 cm

b. Construction

(1) Metal Strip

Drill four holes (diameters approximately 0.1, 0.08, 0.05, and 0.02 cm) in the metal strip (A) at regular intervals.

c. Notes

(i) Circular diffraction patterns may be studied with these holes and the Light Source (VI/A1) placed in such a position that the light filament is viewed through the small hole in the lid of the lamp housing, thus acting as a point source. If this point source is viewed at a distance of about three meters by looking through one of the diffraction holes, when the strip is held close to the eye, a diffraction pattern will be seen even in daylight conditions. The pattern will appear clearer if the Filter (VI/C4) is placed in front of the diffraction hole.

E4. Interference Strips

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Metal Strip	1	Metal Strip (Copper or Steel)	14 cm x 1 cm x 0.1 cm
(2) Handle	1	Wood	7 cm x 1 cm x 1 cm

b. Construction

(1) Metal Strip

The metal strip (A) may be of any desired metal. In this instance, two are specifically recommended, namely copper and steel (from packing case bands).

(2) Handle

Slit

4

The handle is made from the wood (B). Cut a slit down the middle of the handle with a saw. Cement the metal strip into this inset with epoxy resin.

c. Notes

(i) If the end of the metal strip is placed in a hot flame, interference bands will be produced on the strip.

VII. LABORATORY ACCESSORIES

Where a science room has an electric outlet teachers will wish to take advantage of the mains' supply. The apparatus described here considerably extends the usefulness of the electric outlet.

A. TRANSFORMERS

This section describes different types of transformers which may be used to produce low voltage AC outputs. The limitations of each transformer are carefully described in the notes.

B. RECTIFIERS

This section describes rectifiers, which may be used with the foregoing transformers, to produce low voltage DC current.

A. TRANSFORMERS

A1. Transformer, Iron Wire Core (6 volt output, 120 volt mains)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coils	1	Sheet of Cardboard (A)	12 cm x 7.5 cm
	1	Roll of Magnet Wire (B)	#24, 250 g
	1	Roll of Magnet Wire (C)	#20, 60 g
	1	Roll of Masking Tape (D)	--
(2) Core	1	Galvanized Wire (E)	#12, 30 meters
	--	Varnish (F)	--
	1	Bolt (G)	0.5 cm diameter, 14 cm long
	1	Nut (H)	0.5 cm internal diameter
	2	Washers (I)	4 cm external diameter
(3) Base	1	Wood (J)	20 cm x 15 cm x 1.5 cm
	1	Wood (K)	15 cm x 3 cm x 2 cm

4	Bolts (L)	2.5 cm long, 0.3 cm diameter
8	Nuts (M)	0.3 cm internal diameter
--	Insulation Tape (N)	--

b. Construction

(1) Coils

Cut a piece of wood (10 cm x 3 cm x 3 cm) to serve as a winding block for the primary and secondary coils. Take the sheet of cardboard (A) and use a razor blade to score parallel lines on it at 3 cm intervals so that it may readily be bent to the shape of the wooden block.

Wrap the cardboard around the block, fastening the two loose edges together with masking tape (D), thus producing a cardboard holder on which to wind the coils.

Wind 800 turns of #24 magnet wire (B), approximately 250 g, on to the cardboard holder to make the primary coil, leaving about 10 cm of wire free at

both ends. To do this a system of winding such as that described under IX/A2 should be adopted. (A variation is described in the notes below.) Wind the turns on to only the middle 6 cm or so of the cardboard holder. After winding each additional layer of turns, temporarily remove the cardboard holder (and turns) from the winding block, and cover the turns with masking tape. This not only holds the new layer of turns in position, but also insulates it from the next layer to be added.

Next, take wire (C), and wind 40 turns, approximately 60 g, on top of the primary coil following the same procedures described for the primary coil, but in this case making each layer only about 3.5 cm long, instead of 6 cm. As before, insure that each layer of turns is insulated from the next with masking tape, and that some 10 cm of wire is left free at both ends of the coil. The newly added coil is appropriately labeled the secondary coil.

(2) Core

Cut the galvanized iron wire (E) into a series of 20 cm lengths. Dip these in varnish (F), and then lean them against a vertical surface to dry, in such a way that varnish is not removed from the wire in the process of drying. One to two days will be required for the varnish to dry.

Take the dry wires one at a time, and bend them through, and around, the coil so that the wire ends just touch, or overlap, one another. If the wire is too long, cut the ends. Continue adding the iron wires to the coil in the same way, distributing the wires equally on each face of the coil, until the coil is almost full of iron wire. However, leave enough space to squeeze bolt (G) through the middle of the wire core.

Slide bolt (G) through the middle of the iron wires. Washers (I) should be fitted on either end of the bolt, and the whole kept in position with a suitable nut (H).

(3) Base

Make the base from wood (J). Drill a hole (diameter 0.5 cm) through the center, and attach the coil and core to the base with the help of the bolt (G) through the middle of the core. Make an inset in the bottom of the base to accommodate the bolt-head.

Use the bolts (L) and nuts (M) to make four terminals (as described under VIII/A2). Fit two at one end of the base to serve as secondary terminals, and attach the ends of the secondary coil to these, after cleaning the ends of the wire with sandpaper. Fit the other two terminals at the other end of the base to serve as the primary terminals. Attach the ends of the primary coil to the terminals after cleaning the ends of the wire with sandpaper. Remembering that the primary coil will be connected to the mains (120 volts) it is important to insure good insulation of all primary terminals and wires. Therefore, cover each of the wires from the primary coil to the relevant terminal with electrical insulation tape (N). In addition make a safety cover from wood (K). Simply cut holes (2 cm deep,

1 cm diameter) in the under-surface of the wood to accommodate the terminals, and set the wood on the base so that it covers the terminals.

c. Notes

(i) A convenient way of winding the coils is to use a hand drill and winding block. Clamp the hand drill horizontally above the bench surface, and hold a winding block horizontally in the drill chuck with the help of a screw fixed firmly in the end of the winding block. If a cardboard sleeve is fitted over the winding block, the wire may be wound on the sleeve, and the latter subsequently removed complete with newly wound coil.

(ii) The transformer made and tested here actually had 800 turns on the primary and 43 turns on the secondary. The voltage output was noted to be 6.6 volts when the current load was at a minimum, and that it fell to 5.5 volts as the load increased to 4 amps. At the same time the efficiency of the transformer increased from 32% at 6.6 volts to 45% at 5.5 volts.

(iii) Tested under a continuous load of 4 amps, the temperature of the core rose to 69°C over a period of 50 minutes, at which point the load was cut off to prevent

serious overheating of the core. The data, indicated below, suggested that this transformer could be used continuously under a load of 3 amps, but with a load of 4 amps it should not be used for periods exceeding 30 minutes at any given time.

Room Temperature	Output Voltage	Output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	5.5	4	0	24
			20	50
			40	64
			50	68
			Testing stopped after 50 min	

Under the smaller load of 2.8 amps the core heated up more slowly, stabilizing at 62°C.

Room Temperature	Output Voltage	Output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	6.0	2.8	0	24
			20	46
			40	56
			60	62

A2. Transformer, Sheet Iron Core (12 volt output, 120 volt mains)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coils	1	Sheet of Cardboard (A)	12 cm x 7.5 cm
	1	Roll of Magnet Wire (B)	#24, 250 g
	1	Roll of Magnet Wire (C)	#20, 100 g
	1	Roll of Masking Tape (D)	--
(2) Core	60	Galvanized Iron Sheets (E) (more sheets required if thinner sheeting is used)	13 cm x 10 cm x 0.05 cm
	5	Bolts (F)	0.3 cm diameter, 3.5 cm long
	5	Nuts (G)	0.3 cm internal diameter
	--	Varnish (H)	--
(3) Vertical Support	1	Galvanized Iron or Aluminum Sheet (I)	47.5 x 5 x 0.02 cm
(4) Base	1	Wood (J)	30 cm x 15 cm x 1.5 cm
	1	Wood (K)	15 cm x 3 cm x 2 cm
	4	Bolts (L)	2.5 cm long, 0.3 cm diameter
	8	Nuts (M)	0.3 cm internal diameter

-- Insulation Tape (N) --

b. Construction

(1) Coils

Follow the instructions given with the foregoing transformer (VII/A1) for the construction of the coils. Make a form, on which to wind the coils, from the cardboard sheet (A), and wind 800 turns of magnet wire (B) on to the form to make the primary coil. Then wind 80 turns (not 40) of magnet wire (C) on to the coil to make the secondary coil.

(2) Core

Stack the sheets of galvanized iron (E) one on top of the other, until they make a pile 2.8 cm thick. This will require 55, or more, sheets, dependent on the thickness of each. Then cut each sheet as illustrated to form a W-shaped core piece and a rectangular crosspiece.

Stack the newly cut plates back on top of each other, and drill five bolt holes (diameter 0.4 cm) through the plates. A drill press is preferred for this purpose, but it is possible to hand drill each plate separately. Use nuts (G) and bolts (F) to

fasten the plates of the cross-piece and core together.

Take a file to smooth off the rough edges of the newly made core. It is important that the finished surfaces should insure good contact between the top of the W-shaped core and the crosspiece.

Now take the plates apart, paint varnish (H) on each in turn, reassembling the plates while still wet. The varnish acts as an insulator, which reduces eddy currents, and hence heating effects, within the core. The core may take one or two days to dry.

Assemble the coils on the W-shaped core, using paper or wood wedges if necessary to insure the coil is held firmly on the central upright of the core.

(3) Vertical Support

Use galvanized iron or aluminum sheeting (I) to make the vertical support. Cut it to the dimensions indicated, and bend it into the shape of a bridge. Drill two holes (diameter 0.3 cm) in either foot of the bridge so that the support may subsequently be attached to a base with screws.

(4) Base

Make a base for the transformer out of wood (J). Fit the vertical support snugly over the core and coils, and attach the support to the middle of the base with screws.

Use bolts (L) and nuts (M) to make four terminals [as described under VIII/A2, Component (4)]. Fit two at one end of the base to serve as secondary terminals, and attach the ends of the secondary coil to these after cleaning the ends of the wire with sandpaper. Fit the other two terminals at the other end of the base to serve as the primary terminals. Attach the ends of the primary coil to the terminals after cleaning the ends of the wire with sandpaper. Remembering that the primary coil will be connected to the mains (120 volts), it is important to insure good insulation of all

primary terminals and wires. Therefore, cover each of the wires from the primary coil to the relevant terminal with electrical insulation tape (N).

In addition, make a safety cover for the primary terminals from wood (K). Simply cut holes (2 cm deep, 1 cm diameter) in the undersurface to accommodate the terminals, and set the wood on the base so that it covers the terminals.

c. Notes

(i) The voltage output of the secondary coil of the transformer will be at a maximum when the current load is at a minimum. In this case it was noted that the output voltage fell from 12 volts at 1 amp to 11 volts at 4 amps. At the same time the efficiency of the transformer increased from 47% at 12 volts to 62% at 11 volts.

(ii) Tested over a period of 90 minutes under a continuous load of 4 amps, the temperature of the core remained well within acceptable limits. The following data indicates the degree of heating somewhat more explicitly.

Room Temperature	Output Voltage	Output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	10.8	4	0	24
			20	52
			40	56
			60	59
			90	59

Under smaller loads the core heats up more slowly, but observations tended to suggest that the ultimate equilibrium temperature achieved (59°C) was the same as with the heavier load. (See table on next page.)

Room Temperature	Output Voltage	Output Amperage	Running Time	Core Temperature
°C	Volts	Amps	Minutes	°C
24	11	3	0	24
			20	44
			40	52
			60	59

A3. Transformer, Variable Output (120 volt mains)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coils	1	Cardboard Sheet (A)	13.0 cm x 11.5 cm
	1	Roll of Magnet Wire (B)	#24, 250 g
	1	Roll of Magnet Wire (C)	#20, 250 g
	1	Masking Tape (D)	--
(2) Core	60	Galvanized Iron Sheets (E) (more sheets required if thinner sheeting is used)	17 cm x 10 cm x 0.05 cm
	5	Bolts (F)	0.3 cm diameter, 3.5 cm long
	5	Nuts (G)	0.3 cm internal diameter
	1	Can of Varnish (H)	--
(3) Vertical Support	1	Galvanized Iron or Aluminum Sheet	55.5 cm x 5 cm x 0.02 cm
(4) Base	1	Wood (J)	30 cm x 20 cm x 1.5 cm
	1	Wood (K)	20 cm x 3 cm x 2 cm

9	Bolts (L)	2.5 cm long, 0.3 cm diameter
18	Nuts (M)	0.3 cm internal diameter
1	Roll of Insulation Tape (N)	--

b. Construction

(1) Coils

Cut a piece of wood (14 cm x 3.2 cm x 3.2 cm) to serve as a winding block for the primary and secondary coils. Take the thin sheet of cardboard (A) and use a razor blade to score parallel lines on it at intervals of 3.25 cm, so that the cardboard may readily be bent around the wooden block.

Wrap the cardboard sheet around the block, fastening the loose edges together with masking tape (D), thus producing a cardboard form on which to wind the primary and secondary coils.

To make the primary coil, wind 720 turns (approximately 250 g) of magnet wire (B), onto the cardboard form. Each layer of turns will be 10 cm long. Place masking tape between each layer. The actual method of winding is described under VII/A1.

To make the secondary coil, wind 180 turns (approximately 250 g) of magnet wire (C) on top of the primary coil in the usual way (leaving a free end about 20 cm long at the start). However,

halt after every 30 turns to make a tap. (The latter is made by taking the next 40 cm of wire, folding it to make a double strand, and twisting it around itself.) Then continue for another 30 turns before making a further tap, again with a 40 cm length of wire. It is very important to make the taps at the corners of the secondary coil, otherwise they will interfere with the placement of the coil on the core. Each layer of turns should be covered in the usual way with masking tape to insulate it from the next layer. In all, there should be taps after 30, 60, 90, 120 and 150 turns, and a free end (20 cm long) after 180 turns.

(2) Core

Stack the galvanized iron sheets (E) on top of the other until the pile is 2.8 cm thick. This will require 55, or more, plates, dependent on the thickness of the sheet. Then cut each of the sheets as illustrated to form a W-shaped plate and a rectangular crosspiece.

Stack the newly cut plates back on top of each other, and drill 5 bolt holes (diameter 0.4 cm) through the plates. A drill press is preferred for this purpose, but it is possible to hand drill each plate separately. Use nuts (G) and bolts (F)

to fasten the plates of the crosspiece and core together.

Take a file to smooth off the rough edges of the newly made core. It is important that the finished surfaces should insure good contact between the top of the W-shaped core and the crosspiece.

Now take the plates apart, and cover each in turn with varnish (H), reassembling the plates while still wet. The varnish acts as an insulator, which reduces eddy currents, and hence heating effects, within the core. The core may take one or two days to dry.

Assemble the coils on the W-shaped core, using paper or wood wedges if necessary to insure the coil is held firmly on the central upright of the core.

(3) Vertical Support

Use galvanized iron or aluminum sheeting (I) to make the vertical support. Cut it to the dimensions indicated, and bend it to the shape of a bridge. Drill two holes (diameter 0.3 cm) in either foot of the bridge so that the support may subsequently be attached to a base with screws.

Make a base for the transformer out of wood (J). Fit the vertical support snugly over the core and coils, and attach the support to the middle of the base with screws.

Use bolts (L) and nuts (M) to make nine terminals [as described under VII/A2, Component (4)]. Fit seven at one end of the base to serve as secondary terminals, and attach the ends of the secondary coil and the taps to these after cleaning the ends of the wire and taps with sandpaper. Cover the wires with insulation tape (N) or tubing to prevent any possibility of a short. Fit the other two terminals at the other end of the base to serve as the primary terminals. Attach the ends of the primary coil to the terminals after cleaning the ends of the wire with sandpaper. Remembering that the primary coil will be connected to the mains (120 volts),it is important to insure good insulation of all primary terminals and wires. Therefore, cover each of the wires from the primary coil to the relevant terminal with electrical insulation tape.

In addition, make a safety cover for the primary terminals from wood (K). Simply cut holes (2 cm deep, 1 cm diameter) in the undersurface to accommodate the terminals, and set the wood on the base so that it covers the terminals.

c. Notes

(i) Do not expect the output voltages to be exactly 5, 10, 15 volts and so on. With the apparatus produced and tested here the output voltages, observed by combining any one tap with the coil endpiece, were 4.5, 10.0, 15.0, 21.0, 26.3 and

31.0 volts when the primary voltage was 121 volts.

(ii) The transformer was tested using the 10, 20 and 30 volt outputs. As expected, it was noted that the transformer operated more efficiently at the higher voltages.

The voltage output from any given pair of terminals was observed to fall as the current output increased. Actual results are tabulated below.

Output Taps = 30 volts

Input	Output				
*Power Watts	I Amps	V Volts	R Ohms	*Power Watts	Efficiency %
46	1.00	28.4	28.4	28.40	62
52	1.25	28.0	22.4	35.00	67
59	1.50	27.5	18.3	41.25	70
68	1.75	27.0	15.4	47.25	69
75	2.00	26.5	13.2	53.00	71
82	2.25	26.0	11.5	58.50	71
90	2.50	25.5	10.2	63.75	71
97	2.75	25.0	9.1	68.75	71
105	3.00	24.0	8.0	72.00	69

* Power was measured directly with wattmeters.

Output Taps = 20 volts

Input	Output				
*Power Watts	I Amps	V Volts	R Ohms	*Power Watts	Efficiency %
33	0.75	19.5	26.0	14.6	44
38	1.00	19.2	19.2	19.2	50
43	1.25	19.0	15.2	23.7	55
48	1.50	18.5	12.3	27.7	58
52	1.75	18.3	10.4	32.0	61
56	2.00	18.0	9.0	36.0	64
61	2.25	17.7	7.9	39.8	65
66	2.50	17.5	7.0	43.7	66
71	2.75	17.0	6.2	46.7	66
76	3.00	16.5	5.5	49.5	65

Output Taps = 10 volts

Input	Output				
*Power Watts	I Amps	V Volts	R Ohms	*Power Watts	Efficiency %
22	0.50	9.0	18.0	4.5	20
24	0.75	8.8	11.7	6.6	27
26	1.00	8.7	8.7	8.7	33
29	1.25	8.6	6.9	10.7	37
31	1.50	8.4	5.6	12.6	41
34	1.75	8.3	4.7	14.5	43
36	2.00	8.1	4.0	16.2	45
38	2.25	8.0	3.5	18.0	47
40	2.50	7.8	3.1	19.5	49
43	2.75	7.7	2.8	21.2	49
45	3.00	7.6	2.5	22.8	51

* Power was measured directly with wattmeters.

(iii) Some heating of the transformer was noted, but this appeared to be within acceptable limits. Hence, when a current of 3 amps was drawn from the maximum voltage taps (30 volts) the temperature of the transformer core did not rise beyond 60° Centigrade.

Output Taps = 30 volts
Output = 3 amps at 24 volts
Room Temperature = 24°C

Running Time (Minutes)	Core Temperature (Degrees Centigrade)
0	27° C
5	38° C
10	48° C
15	49° C
20	51° C
25	53° C
40	56° C
50	58° C
60	59° C

B. RECTIFIERS

B1. Sodium Bicarbonate Rectifier (2 Plate)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Cell Containers	4	Glass Jars (A)	Approximately 300 ml, 10 cm diameter
(2) Base	1	Plywood Sheet (B)	22 cm x 22 cm x 0.5 cm
	1	Wood Strip (C)	22 cm x 2 cm x 2 cm
	2	Wood Strips (D)	10 cm x 2 cm x 2 cm
	4	Wood (E)	2 cm x 2 cm x 1 cm
(3) Plates Support	2	Wood (F)	15 cm x 1.5 cm x 1.5 cm
	2	Wood (G)	12 cm x 1.5 cm x 1.5 cm
(4) Plates	4	Lead Sheets (H)	6.5 cm x 5.0 cm x 0.02 cm
	4	Aluminum Sheets (I)	6.5 cm x 5.0 cm x 0.02 cm
	8	Bolts (J)	0.3 cm diameter, 2.5 cm long
	8	Nuts (K)	0.3 cm internal diameter

	16	Washers (L)	0.3 cm internal diameter, approximately
	4	Filter Papers (M)	5.5 cm x 5.5 cm
	1	Saturated Solution of Sodium Bicarbonate (N)	1 liter
(5) Wiring	1	Roll of Magnet Wire (O)	#24

c. Construction

(1) Cell Containers

To make a cell container, take jar (A), and use a hot nichrome wire (CHEM/I/F2) to cut the top off the jar some 6 cm above the base. Repeat the process with three more jars.

(2) Base

Plywood Base (B)

Nail wood strips (C,D) to the top of the plywood sheet (B) so as to divide it into four equal portions. Nail the wood strips (E) at the corners of the plywood in such a way that the four cell containers, placed in the appropriate quarters, will be held in position on the plywood base.

(3) Plates Support

Use wood Strips (F) and (G) to make the frame of the plate support. Drill two bolt holes (0.3 cm diameter) in each side of the support, such that the holes in any one side are 4 cm apart, and are equidistant from the center of the side.

(4) Plates

Cut a plate out of lead sheeting (H) and another out of aluminum sheeting (I) to the dimensions shown. Drill a hole (0.3 cm diameter) in the projecting portion of each plate.

Attach the lead plate to the plate support with the help of bolt (J), nut (K) and washers (L) placed either side of the plate.

Attach the aluminum plate to the plate support in the same way, but so that the aluminum plate lies on top of the lead

plate. Place the sheet of filter paper (M) between the two plates, thus insulating one from the other.

Cut three more lead plates and three more aluminum plates, and make identical plate pairs (insulated with filter paper) for the three remaining sides of the plate support.

Rest the plate support on the four cut jars, such that one pair of plates is suspended in each jar.

Almost fill each jar with a saturated solution of sodium bicarbonate (N), that is baking soda, and add a little extra sodium bicarbonate to each cell to insure that the solution remains saturated during use.

(5) Wiring

Use copper wire (O) to connect the plates of the four cells together, as indicated in the diagram. The cells have the simple property of permitting electrons to flow only in one direction, from aluminum to lead, and when connected as indicated to an AC source a rectified output is obtained. The type of output obatined with AC sources of 12 volts and 25 volts is indicated in the notes.

c. Notes

(i) The AC voltage supply may be taken from the transformer already described (VII/A3). A series of tests were conducted on the rectifier produced here, after it had been running for one hour. The results are tabulated below.

(ii) With a variable resistance (R) connected across the DC output it will be noted that the output voltage (V_r) fell off as the resistance decreased. [A very small proportion of the fall in voltage may be attributed to the drop in voltage (V_t) from the transformer.]

AC Supply = 15 volt taps

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
820	15.7	0.10	1.57	8.2	0.01	0.08	5.2
800	15.6	0.11	1.71	8.0	0.01	0.08	4.7
390	15.6	0.15	2.34	7.8	0.02	0.16	6.7
172	15.5	0.20	3.10	6.9	0.04	0.28	8.9
98	15.5	0.21	3.26	5.9	0.06	0.35	10.8
84	15.4	0.25	3.86	5.9	0.07	0.41	10.7
70	15.3	0.30	4.59	5.6	0.08	0.45	9.8
60	15.3	0.30	4.59	5.4	0.09	0.49	10.6
52	15.3	0.30	4.59	5.2	0.10	0.52	11.3
42	15.2	0.30	4.56	5.0	0.12	0.60	13.2
31	15.1	0.35	5.28	4.6	0.15	0.69	13.1
21	15.1	0.45	6.80	4.2	0.20	0.84	12.3
11	15.0	0.61	9.15	3.4	0.31	1.05	11.5
9	14.9	0.75	11.18	3.2	0.37	1.18	10.6
6	14.8	0.95	14.06	2.8	0.45	1.26	8.9
5	14.5	1.05	15.23	2.6	0.50	1.30	8.5
3	14.0	1.35	18.90	1.9	0.68	1.29	6.8

AC Supply = 25 volt taps

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
1,850	25.9	0.48	12.43	18.5	0.01	0.18	1.5
910	25.9	0.48	12.43	18.2	0.02	0.36	2.9
583	25.9	0.50	12.95	17.5	0.03	0.53	4.1
435	25.9	0.50	12.95	17.4	0.04	0.70	5.4
275	25.8	0.55	14.19	16.5	0.06	0.99	7.0
200	25.8	0.60	15.48	16.0	0.08	1.28	8.3
97	25.2	0.70	17.64	14.5	0.15	1.45	8.2
89	25.1	0.75	18.82	14.2	0.16	2.27	12.1
78	25.1	0.78	19.58	14.0	0.18	2.52	12.9
69	25.0	0.80	20.00	13.8	0.20	2.76	13.8
61	25.0	0.85	21.25	13.5	0.22	2.97	14.0
50	24.8	0.95	23.56	13.0	0.26	3.38	14.4
39	24.5	1.05	25.73	12.5	0.32	5.00	19.4
30	24.0	1.22	29.28	12.0	0.40	4.80	16.4
20	23.5	1.52	35.72	11.0	0.55	6.05	16.9
10	22.2	2.15	47.73	9.0	0.88	7.82	16.4

(iii) The current output of the rectifier was very low, but was noted to increase when the voltage from the transformer was increased. Thus with a resistance of 10 ohms in the external circuit the DC current produced was 0.34 or 0.88 amps according to whether the rectifier was connected to the 15 or 25 volt taps on the transformers.

(iv) The rectifier was extremely inefficient in its use of power. The maximum efficiency on the 15 volt taps was noted to be 13% and on the 25 volt taps to be 19%.

(v) It was noted that not only did the output voltage (V_r) from the rectifier decrease with increasing resistance (R), but that there was also some variation of the voltage (V_r) at a fixed resistance (R) with the passage of time. These factors suggest that although the apparatus is capable of producing a DC current, the latter is not suitable for quantitative (as opposed to qualitative) experimentation.

B2. Silicon Rectifier

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	15 cm x 10 cm x 2 cm
(2) Rectifiers and Supports	4	Silicon Rectifier Diodes (B)	1N1341
	4	Brass Bars (C)	7 cm x 2 cm x 0.3 cm
(3) Electrical Connections	2	Brass Strips (D)	5 cm x 1 cm x 0.5 cm
	1	Brass Strip (E)	5 cm x 3 cm x 0.5 cm
	4	Bolts (F)	0.3 cm diameter, 3.5 cm long
	8	Nuts (G)	0.3 cm internal diameter
	1	Copper Wire (H)	#20, 40 cm long

b. Construction

(1) Base

Use wood (A) as the base.

(2) Rectifiers and Supports

Purchase four silicon rectifier di-des (B) from a radio shop or electrical supply house. Ask for a rectifier identified as a 1N1341. This will be capable of handling a peak reverse

voltage of 50 volts, a continuous forward current of 6 amps and a maximum surge of 30 amps.

Take a brass bar (C) and bend it at right angles, 4 cm from one end, to form an L-shaped support. Drill a hole (0.5 cm diameter) in the middle of the long upright of the support and a hole (0.3 cm diameter) in the base of the support. Screw one of the rectifier diodes in the upright portion of the support. Attach the three remaining diodes (B) to three identical supports (C) in the same way. Attach the four supports to the base (A). It should be noted that the supports also act as heat sinks, removing heat that is generated within the diodes. It is for this reason that the support is made from a thick metal bar.

(3) Electrical Connections

Brass Strip (D)

Terminal Hole

Take the two brass strips (D) and drill a hole (0.3 cm diameter) close to the end of each. Insert the strips under the supports (C) at one end of the base as indicated. Use bolts (F) and nuts (G) to make four terminals (F/G) as described under VIII/A2, Component (4). Fit two of the terminals on the base so that each is connected to a brass strip by means of the appropriate hole.

5.0

1.0

3.0

Brass Strip (E)

1.0

Terminal Hole

Cut an L-shaped strip out of brass sheet (E). Drill a hole (0.3 cm diameter) in the end of the shorter arm, and fit the longer arm beneath the two remaining supports so that they are connected electrically. Fit the two remaining terminals (F/G) to the end of the base, so that one is connected to the L-shaped strip.

Take the copper wire (H) and connect the silicon diodes as illustrated. It will be necessary to solder the wire on to the ends of the diodes, and particular care should be taken to avoid overheating, since this can destroy the diodes.

c. Notes

(i) The rectifier produced is represented diagrammatically here. The reader should compare this with the previous diagram, noting the equivalent components marked by letters of the alphabet.

(ii) With a variable resistance R connected across the DC output it will be noted that the output voltage (V_r) falls off as the resistance decreases, even when the transformer is continuously monitored to keep the voltage (V_t) constant. This pattern of behavior is the same as for the Sodium Bicarbonate Rectifier (VII/B1). However, it will be noted that the efficiency of the Silicon Rectifier varies from 60% to 70% and the rectified current is as great as 3 amps at 5.5 volts. In this respect the Silicon Rectifier is a considerable improvement over the Sodium Bicarbonate Rectifier.

AC Supply = 10 volt taps

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
110	10.2	0.08	0.82	7.7	0.07	0.6	70.4
96	10.2	0.09	0.92	7.7	0.08	0.6	67.4
86	10.2	0.10	1.02	7.7	0.09	0.7	67.9
77	10.2	0.11	1.12	7.7	0.10	0.8	68.7
63	10.2	0.13	1.33	7.6	0.12	0.9	68.6
54	10.1	0.16	1.62	7.6	0.14	1.1	67.9
42	10.1	0.20	2.02	7.6	0.18	1.4	67.7
31	10.1	0.26	2.63	7.5	0.24	1.8	68.4
21	10.0	0.39	3.90	7.4	0.35	2.6	66.7
11	9.9	0.77	7.62	7.2	0.68	4.9	64.2
9	9.8	0.90	8.82	7.0	0.80	5.6	63.5
8	9.8	1.00	9.80	7.0	0.86	6.0	61.2
7	9.7	1.15	11.20	7.0	1.00	7.0	62.5
5	9.6	1.42	13.60	6.8	1.25	8.5	62.3
4	9.4	1.68	15.80	6.6	1.50	9.9	62.6
3	9.3	1.95	18.10	6.4	1.75	11.2	61.9
2	8.7	3.05	26.50	5.8	2.75	15.9	60.2
1	8.6	3.35	28.80	5.6	3.00	16.8	58.3

AC Supply = Held constant at 10 volts.

Load	Transformer Output			Rectifier Output			Efficiency
R Ohms	V_t Volts	I_t Amps	W_t Watts	V_r Volts	I_r Amps	W_r Watts	%
128	10.0	0.06	0.60	7.7	0.06	0.46	76.7
95	10.0	0.08	0.80	7.6	0.08	0.60	75.0
63	10.0	0.13	1.30	7.6	0.12	0.91	70.0
38	10.0	0.22	2.20	7.6	0.20	1.52	69.1
25	10.0	0.32	3.20	7.6	0.30	2.28	7.13
19	10.0	0.43	4.30	7.5	0.40	3.00	69.8
15	10.0	0.55	5.50	7.5	0.50	3.75	68.2
12	10.0	0.66	6.60	7.5	0.60	4.50	68.2
9	10.0	0.89	8.90	7.4	0.80	5.92	66.5
7	10.0	1.07	10.70	7.4	1.02	7.55	70.6
6	10.0	1.32	13.20	7.3	1.25	9.13	69.2
5	10.0	1.61	16.10	7.3	1.51	11.02	68.4
4	10.0	1.88	18.80	7.2	1.75	12.60	67.0
3	10.0	2.41	24.10	7.2	2.25	16.20	67.2
2	10.0	3.27	32.70	7.1	3.00	21.30	65.1

(iii) The output voltage (V_r) remains extremely steady with the passage of time, making this a much more suitable rectifier for quantitative experimentation than the Sodium Bicarbonate Rectifier.

AC Supply = 10 volt taps

Time	Transformer Output		Rectifier Output	
t Minutes	V_t Volts	I_t Amps	V_r Volts	I_r Amps
1	9.5	1.62	6.6	1.50
2	9.5	1.62	6.6	1.49
3	9.6	1.63	6.6	1.50
4	9.6	1.62	6.6	1.50
5	9.7	1.63	6.6	1.51
10	9.7	1.63	6.6	1.51
15	9.7	1.63	6.6	1.51
20	9.7	1.63	6.6	1.51
25	9.7	1.63	6.6	1.51
30	9.8	1.65	6.6	1.51

VIII. CIRCUIT APPARATUS

A. CELLS

This section contains cells and simple batteries which may serve as suitable sources of electrical energy for typical classroom experiments.

B. CIRCUIT COMPONENTS

The apparatus described here is limited to such typical components as switches and bulb holders.

C. RESISTORS

Fixed and variable resistors for typical classroom experiments are described in this section.

D. DYNAMO/MOTORS

This section contains two motors which may also be used as dynamos. The first is a very simple device which is capable of generating only a very minute current, whereas the second is a much more substantial item which generates sufficient current to light a bulb.

A. CELLS

A1. Chemical Cell ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Container	1	Plastic Container (A)	Approximately 8 cm diameter, 8 cm deep
(2) Plates	1	Zinc Sheet (B)	5 cm x 2 cm x 0.05 cm
	1	Copper Sheet (C)	5 cm x 2 cm x 0.05 cm
	1	Steel Sheet (D)	5 cm x 2 cm x 0.05 cm
	1	Carbon Rod (E)	Extracted from dry cell
	4	Brass Wire (F)	2.5 cm long, 0.1 cm diameter
(3) Holders	2	Wood Holders (G)	10 cm x 1 cm x 1 cm
	1	Bolt (H)	0.3 cm diameter, 1.5 cm long
	2	Nuts (I)	0.3 cm internal diameter

c. Construction

(1) Container

Use a plastic or glass jar (A) as the electrolyte container. (A wide variety of electrolytes

© From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 171-172.

may be used, including commonly available vinegar and household salt solutions.)

(2) Plates

Solder a brass suspension wire (F) on to each of the metal sheets (B, C and D). Also solder a similar suspension wire (F) to the metal cap on a carbon rod (E) extracted from a dry cell.

(3) Holders

In each wood holder (G), drill a vertical suspension hole (0.2 cm diameter) and a horizontal bolt hole (0.3 cm diameter) to meet the vertical hole.

Cross Section

Inset one of the nuts (I) over the bolt hole with a sharp tap of the hammer. (A little epoxy resin will hold the nut permanently in position.) Thread the second nut (I) on to the bolt (H) to serve as a locking nut, and then screw the bolt into the bolt hole. Insert a suspension wire in the vertical hole, and clamp it in position by tightening the bolt.

Electrical leads may be fastened under the locking nuts on the holders, and the cell connected into an electrical circuit.

c. Notes

(i) Any of the two plates in combination with one of the electrolytes mentioned above will produce an electric current. The latter may be detected by means of a simple galvanometer (e.g., X/B1). It is recommended that students compare the magnitudes of currents that can be produced by the various plate and electrolyte combinations.

A2. Dry Cell Holder with Cells ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	18.5 cm x 5.5 cm x 2 cm
(2) Cells	3	Dry Cells (B)	1.5 volts each
(3) Endpieces	2	Brass Sheets (C)	4.0 cm x 1.5 cm x 0.3 cm
	6	Screws (D)	Approximately 0.8 cm long
	1	Bolt (E)	0.4 cm diameter, 2 cm long
	1	Nut (F)	0.4 cm internal diameter
(4) Terminals	4	Brass Bolts (G)	0.3 cm diameter, 2.5 cm long
	8	Nuts (H)	0.3 cm internal diameter
	4	Magnet Wire (I)	#22, 15 cm long

©From Reginald F. Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 123-127.

(5) Contact Plates	2	Circular Brass Sheets (J)	1.5 cm diameter, 0.05 cm thick

b. Construction

(1) Base

Cut the base out of the soft wood (A), and use a curved chisel to make a long groove (about 0.5 cm deep) in the surface to hold the dry cells in position.

(2) Cells

Place three dry cells (B) in series in the groove of the base. The groove should be from 1 to 1.5 cm longer than the three cells placed end to end, thus allowing room for the placing of contacts between the cells, and for adjustment of the screw in one of the end-pieces.

(3) Endpieces

Use the brass sheets (C) for endpieces. Drill three small holes (0.2 cm diameter) at the base of each endpiece to facilitate attachment to the base with the screws (D). Place the dry cells on the base to determine the height of the mid-point of the dry cells, and then drill an inset (0.9 cm diameter, 0.15 cm deep) at this height in one endpiece, and a hole (0.4 cm diameter) at the same height through the other endpiece. Thread the newly drilled hole to take the

Brass Plates (C)

adjustment bolt (E).

Side View

The latter bolt may have to be adjusted with the help of a coin, or some such device. A much more convenient adjustment bolt could be made by a technician, or anyone familiar with a metal lathe, cutting the head and bolt from a single piece of brass. The base in either case would be made from a separate nut (F), firmly attached to the bolt by damaging the threads at the end.

(4) Terminals

Make four terminals from the brass bolts (G) and nuts (H). Two nuts are required for each terminal, one to serve as a locking nut and one as a terminal nut.

Somewhat better nuts, which are more easily adjusted with the fingers, may be made with a metal lathe. The terminal nut should be 0.5 cm thick, while the locking nut should be much thinner (0.2 cm). The diameter of both should be 1.0 cm.

In some localities it is cheaper to purchase terminals on the local market. Check the availability of such items as Fahnstock clips which can replace the above.

Base, Bottom View

Base, Top View

Make four insets (0.2 cm deep) at equal intervals underneath the front side of the base to take the boltheads of the terminals. Insert the four bolts (G) from below, through holes drilled through the base, and attach the locking nuts (H) and terminal nuts (H).

Use copper wire (I) to attach the end terminals to the end-pieces, fastening the bare ends of the wire beneath the terminal locking nuts and brass endpieces. Similarly attach a length of copper wire (I) (15 cm long) to each of the middle terminals.

(5) Contact Plates

Use a nail head, or punch, to make a central inset (1 cm diameter, 0.2 cm deep) in the two brass sheets (J). Solder the two plates to the bare ends of the wire (I) attached to the two middle terminals. The contact plates are placed between the first and second, and second and third cells, thus enabling the apparatus to provide an external circuit with 1.5, 3.0 or 4.5 volts according to the terminals connected to the circuit.

c. Notes

(i) So long as the adjustment bolt is not tightened too tightly, the cells will remain firmly in the base groove. However, should any problem occur (e.g., due to bad alignment of the adjustment screw) the cells could be held more firmly in place by means of clips made from packing case bands.

(ii) The dry cell holder serves as a variable source of potential providing from 1.5 to 4.5 volts, according to the terminals connected into the circuit.

A3. Simple Battery *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Plates	2	Lead Sheets (A)	80 cm x 7.5 cm x 0.01 cm
	2	Lead Sheets (B)	15 cm x 6 cm x 0.01 cm
	2	Thick Blotting Paper (C)	85 cm x 10 cm
	2	Rubber Bands (D)	--
(2) Container	1	Jar (E)	Capacity 1 liter, approximately
	1	Plywood Lid (F)	10 cm diameter, 0.5 cm thick
	2	Terminals (G)	VIII/A2, Component (4)
	1	Sulphuric Acid (H) (Concentrated)	200 ml

*Adapted from Intermediate Science Curriculum Study, Probing the Physical World, Volume 1, Experimental Edition, (Tallahassee, Florida: Florida State University, 1967), pp 1-4.

b. Construction

(1) Plates

Fold one of the small lead sheets (B) down the middle. Repeat the process again, but this time leave the fold open. You now have a tab for attachment to one of the lead plates.

Fit the end of one of the large lead sheets (A) into one of the tabs (B), and fold the tab firmly down over the sheet using a pencil to flatten the tab down. With the lead sheet fully inserted into the tab, fold the tab once more, and smooth it again. You now have one lead plate complete with tab. Now make a second lead plate complete with tab in an identical manner, using the remaining lead sheets (A and B).

Make a plate "sandwich" by placing the blotting paper (C), lead plate, blotting paper (C), lead plate one on top of the other. The tabs should be at opposite ends of the sandwich, but emerging from the same side.

Roll the "sandwich" up into a tight cylinder. One tab will protrude from the center and one from the edge. Hold the plates in the form of a cylinder by wrapping the rubber bands (D) around the cylinder.

(2) Container

Obtain a one liter jar (E), and use the plywood lid (F) to cover the open end of the jar. Bore two holes (0.5 cm diameter) through the lid to accommodate the tabs, one hole being at the center of the lid and the other 2.5 cm away from the first hole. Drill two more holes (0.3 cm diameter), one on either side of the first two holes to accommodate the terminals. Drill a fifth hole (1 cm diameter) anywhere else in the lid to permit addition of the electrolyte.

Cross Section

Push the plate tabs through the two larger holes in the lid (the center tab through the center hole), and fold the top 1.5 cm of each tab over at right angles so that each overlaps the adjacent small hole in the lid. Fit two terminals (G) into the small holes in the lid, and lock a tab under each terminal. Make one liter of electrolyte in a separate container. This may be dilute sulphuric acid or solium sulphate. Sulphuric

acid is the better electrolyte, but from a student point of view it can be dangerous if it is not handled carefully. Many will prefer to use sodium sulphate for this reason.

To make the sulphuric acid electrolyte pour 813 ml of water into a container. Then add 187 ml of concentrated sulphuric acid (H) to the water in very small quantities, letting the acid run down the sides of the container into the water. Much heat will be caused by the interaction. Stir the electrolyte, and allow it to cool before adding more concentrated acid. Before pouring the electrolyte into the battery it must be completely cool. (If a sodium sulphate electrolyte is preferred add 1.0 liter of water to 114 g of solid sodium sulphate and stir.)

Pour the electrolyte carefully through the appropriate hole in the lid until it just covers the plates. The battery is now ready for charging and use.

Level of
Electrolyte

c. Notes

(i) To charge the battery a DC current of one amp at approximately 2.5 to 3.0 volts is required. This is best obtained with the help of a transformer (VII/A3) and rectifier (VII/B2). Connect the rectifier to the 10 volt taps on the transformer, and connect the battery across the rectifier as illustrated. A variable resistor (VIII/C2) should be connected into the circuit to control the current, and an ammeter and voltmeter connected as indicated to monitor the circuit.

Charge the battery for 30 minutes keeping the current steady at one amp by adjusting the variable resistance. (The voltage will not remain constant throughout the charge.)

(ii) Some idea of the strength of the battery may be obtained by discharging it through a five ohm resistor, and noting the current generated over a period of time, and the voltage of the battery output. The results of one such discharge are given below (for the battery with sulphuric acid electrolyte).

t Minutes	V Volts	I Amps
1	1.00	0.40
2	0.40	0.20
3	0.20	0.10
4	0.19	0.04
5	0.19	0.04

The voltage and current output fall off rapidly with time, indicating that the battery in its present state is not suitable for quantitative experimentation.

(iii) A good, strong battery may be produced simply by recharging the battery and discharging it several times over. This process is more successful if the direction of the current is changed for each recharge. The battery tested above was charged four more times (each time with reversed polarity) and discharged for five minutes through the five ohm resistor after each charge. After each discharge the battery terminals were shorted to remove any remaining charge. The results of the fifth discharge show that the battery, after repeated charging and discharging, is capable of maintaining a steady current output at a steady voltage, and as such is suitable for quantitative experimentation.

t Minutes	V Volts	I Amps
1	1.9	0.39
2	1.9	0.39
3	1.9	0.39
4	1.9	0.39
5	1.8	0.35

(iv) Some idea of the strength of the battery is obtained by comparing the discharge of a small dry cell (through a five ohm resistor) with the above observations. The results indicate that the dry cell is not as steady a source of current and voltage as the battery after successive recharging, but that it is much steadier than the battery after only one charge.

t Minutes	V Volts	I Amps
1	1.39	0.25
2	1.37	0.25
3	1.36	0.24
4	1.35	0.24
5	1.35	0.24

(v) Somewhat similar results are obtained if the battery is filled with sodium sulphate electrolyte and tested in the same way.

B. CIRCUIT COMPONENTS

B1. Bulb Holder with Bulb

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	7 cm x 3 cm x 1 cm
(2) Bulb Holder	1	Bulb Holder (B)	To hold flashlight bulbs
	1	Bulb (C)	1.1, 2.5, or 6.2 volts
(3) Terminals	2	Brass Bolts (D)	0.3 cm diameter, 2.5 cm long
	4	Nuts (E)	0.3 cm internal diameter
	2	Magnet Wire (F)	4 cm long

b. Construction

(1) Base

Use the wood (A) to serve as the base of the bulb holder.

(2) Bulb Holder

Obtain a bulb holder (B) (porcelain or metal) from the local market, and screw it onto the base. The holder should take a

variety of local bulbs (C) (e.g., 1.1 volts, 2.5 volts and 6.2 volts).

(3) Terminals

Make the terminals from the nuts (E) and bolts (D) as described in item VIII/A2, Component (4). Use the magnet wire (F) to connect the bulb and terminals, not forgetting to clean the ends of the wire.

c. Notes

(i) Bulbs may be used not only to investigate electrical phenomena in simple circuits, but also tc serve as suitable resistances.

B2. Switch ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	7 cm x 3 cm x 1 cm
(2) Terminals	2	Brass Bolts (B)	0.3 cm diameter, 2.5 cm long
	4	Nuts (C)	0.3 cm internal diameter
(3) Contact Point	1	Brass Screw (D)	0.8 cm long
	1	Magnet Wire (E)	#22, 3 cm long
(4) Spring	1	Brass Sheet (F)	5 cm x 1 cm x 0.1 cm
	1	Wooden Dowel (G)	1 cm diameter, 0.5 cm long

b. Construction

(1) Base

Use the wood (A) to serve as the base of the switch.

(2) Terminals

Make the terminals from the nuts (C) and bolts (B) as described in item VIII/A2, Component (4).

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(3) Contact Point

Top View

Screw the brass screw (D) into the wood (2 cm from one terminal) and connect it to the terminal by means of the short length of copper wire (E).

(4) Spring

Side View

Make the spring out of the piece of brass sheeting (F). Drill a small hole (0.3 cm diameter) in one end of the spring so that the terminal bolt will pass through it, and hold the spring in position by fastening the terminal locking nut. Cut the wooden head (G) and attach it to the free end of the spring with epoxy resin.

B3. Circuit Board

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Plywood (A)	33 cm x 30 cm x 0.6 cm
	2	Wood (B)	33 cm x 2 cm x 0.5 cm
(2) Cell Holder	2	Wood (C)	30 cm x 2 cm x 2 cm
	3	Dry Cells (D)	1.5 volts each
	2	Metal Strips (E)	4 cm x 2 cm x 0.02 cm
	2	Metal Strips (F)	6 cm x 2 cm x 0.02 cm
	4	Bolts (G)	0.3 cm diameter, 4 cm long
	4	Nuts (H)	0.3 cm internal diameter
	8	Washers (I)	Approximately 1.2 cm external diameter
(3) Terminals	12	Bolts (J)	0.3 cm diameter, 4 cm long
	12	Nuts (K)	0.3 cm internal diameter
	24	Washers (L)	Approximately 1.2 cm external diameter
(4) Circuit Connectors	12	Coat Hanger Wire (M)	10 cm long
	10	Metal Strips (N)	6 cm x 1.5 cm x 0.02 cm

	5	Copper Wires (O)	#18, 25 cm long
(5) Bulb Holders	3	Wood (P)	5 cm x 3 cm x 2 cm
	3	Coat Hanger Wires (Q)	6 cm long
	3	Eye Screws (R)	Approximately 3 cm long
	6	Screws (S)	1 cm long, approximately
	3	Washers (T)	--
	3	Metal Sheets (U)	3 cm x 2 cm x 0.02 cm
	--	Assorted Flashlight Bulbs (V)	--

b. Construction

(1) Base

Botton View

Drill 12 holes (diameter 0.3 cm) through the plywood (A) in the positions indicated. If a piece of scrap wood is placed beneath the plywood during drilling the bottom edges of the hole will not splinter so readily.

Glue the two strips of wood (B) along the bottom edges of the base, at right angles to the grain of the wood, so that bending or warping of the base is prevented.

(2) Cell Holder

Use two pieces of wood (C) to serve as the cell holder strips. Using nails and glue attach one strip to the end of the base which has not yet been drilled with holes. Place the second strip parallel to, and about 3 cm away from, the first strip. Adjust the separation between the two strips so that they will hold three dry cells (D) snugly in position. Then glue and nail the second strip firmly in position.

Drill four holes (diameter 0.3 cm) between the two strips as illustrated.

The two strips of flexible metal (E) may be cut from a tin can (or similar source). Drill a hole (0.3 cm diameter) in the end of each sheet, and then bend the sheet into the shape of an end contact, as indicated. Use sandpaper to remove any coating which might interfere with good electrical contact.

Two more metal strips (F) may be cut from the same source as before. Drill a hole (0.3 cm diameter) at the mid-point of each strip, and then bend each, as indicated, into the shape of a center contact. Use sandpaper to remove any coating which might interfere with good electrical contact.

Side View
(Cross-section)

Mount the contacts in position on the circuit board base, in each instance using a bolt (G), a nut (H) and two washers (I). The purpose of the washers is to hold the bolts (which also serve as terminals) rigidly in a vertical position.

Side View

(3) Terminals

Fit 12 terminals in the remaining holes in the base. Each terminal is made in the same way as described above, each consisting of a bolt (J), a nut (K) and two washers (L).

(4) Circuit Connectors

Remove any paint or coating from the wires (M) with sandpaper. Bend one end of each wire into a loop, and slip this onto one of the terminals. Bend the free end of the wire around an adjacent terminal so as to form a spring catch. Make a small lip on the end of the catch, thus permitting the catch to be readily attached to, or released from, an adjoining terminal.

The ten strips of metal (N) may be cut from a tin can or similar source (brass sheet, etc.). Clean the surfaces with sandpaper. Bend each sheet into a "U" shape in which the sides are 0.4 cm apart. Then place a nail (0.2 cm diameter) between the sides of the "U" sheet, and squeeze the sheet on either side of the nail with pliers to form a small groove. Make small lips on the open ends of the "U" sheet to permit easy attachment to the terminal posts. Finally, attach each end of each copper wire (O) to one of the newly created clips with the help of solder. You should now have twelve coat hanger wire connections and five copper wire connections for completing circuits.

(5) Bulb Holders

Side View

Drill a vertical hole (1.0 cm diameter, 1 cm deep) into the middle of the top surface of the wood (P). Drill a horizontal hole (0.3 cm diameter) into the middle of one end of the block, so as to meet the first hole.

Clean the surface of the wire (Q) with sandpaper. Insert one end of the wire fully into the horizontal hole, and using a pair of dog-nosed pliers (inserted through the vertical hole) bend a loop into the inserted end of the wire. Insert a small screw (S) through the loop to attach the wire permanently within the block.

Cross Section

Fit an eye screw (R) into the middle of the other end of the block, and finally make a spring catch in the free end of the coat hanger wire (Q) (in just the same way as for the circuit connectors) so that the holder may be readily connected between adjacent terminals on the circuit board.

Cross Section

The flexible sheet of metal (U) may be cut from a tin can, or similar source (thin brass sheet). Drill a bulb hole (diameter 0.9 cm) and screw hole (diameter 0.3 cm) in the sheet as indicated. Make a cut in the sheet between one outer edge and the bulb hole. If one side of the slit is raised slightly higher than the other, the hole will serve as a screw socket for a bulb (V). Use a small screw (S) and washer (T) to attach the metal sheet to the top of the block so that the bulb hole in the sheet sits over the hole in the block.

The screw (S) should also be centered on the block so that it makes contact with the threads of the eye screw (R). (If this adjustment is found difficult, contact between the two screws may be made by soldering a short length of copper wire from one screw to the other.)

Three identical bulb holders should be made, each with a selection of bulbs (V) (e.g., 1.1 volts, 2.5 volts, 6.2 volts).

c. Notes

(i) The Circuit Board is a very convenient way of setting up electrical circuits. A typical series of experiments using such a circuit board will be found in Nuffield Foundation, Nuffield Physics, Guide to Experiments 2, (London: Longmans/ Penguin Books, 1967), pp 16-63.

C. RESISTORS

C1. Variable Resistor (Carbon)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	20 cm x 3 cm x 1 cm
(2) Pencil	1	Pencil (B)	20 cm long, approximately
(3) Clips	2	"U" Tacks (C)	--
(4) Wires	2	Copper Wires (Cotton or Plastic Covered) (D)	#22, 30 cm long

b. Construction

(1) Base — Use wood (A) as the base.

(2) Pencil Resistor — Split a soft lead pencil in half so that the lead (B) protrudes along its axis. It is important that the lead should not be broken or cracked by this process.

(3) Clips — Take two U-shaped tacks (C), normally used for securing electrical leads, and secure the pencil (B) to the base (A). One of the clips should be left relatively loose.

(4) Wires

Cross Section

Take the bare end of a length of copper wire (D), and wrap it around the loose clip, so that when the latter is tapped securely into position the copper wire makes good contact with the pencil lead.

c. Notes

(i) If the resistor is connected into a circuit in series with two dry cells (1.5 volts each) and a flash-light bulb (approximately 1.5 volts), it will be found that increasing the length of pencil lead included in the circuit will diminish the brightness of the bulb, the full length of lead (approximately 20 cm of #2B lead) almost extinguishing the light altogether.

C2. Variable Resistor (Nichrome)

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Resistance Coil	1	Wooden Dowel (A)	26 cm long, 2.5 cm diameter
	1	Asbestos Paper (B)	40 cm x 26 cm
	1	Nichrome Wire (C)	#20, 450 cm long
(2) Coil Support	1	Wood (D)	30 cm x 7.5 cm x 2 cm
	2	Wood (E)	8 cm x 7.5 cm x 2 cm
	2	Plywood (F)	30 cm x 3 cm x 0.7 cm
(3) Sliding Contact	1	Wood Dowel (G)	3 cm diameter, 3 cm long
	1	Wood Dowel (H)	3 cm diameter, 1 cm long
	1	Brass Strip (I)	13 cm x 1 cm x 0.02 cm
	1	Bolt (J)	0.3 cm diameter, 6 cm long
	3	Nuts (K)	0.3 cm internal diameter
	--	Washers (L)	1.2 cm external diameter

(4) Terminals	2	Bolts (M)	0.3 cm diameter, 2.5 cm long
	4	Nuts (N)	0.3 cm internal diameter

b. Construction

(1) Resistance Coil

The dimensions of the apparatus depend very much on the resistance required. In this case a 25 ohm resistor, capable of carrying a current of up to 3 amps was required, and it was decided that this could be achieved by using some 400 cm of #20 nichrome wire which had a resistance of approximately 1 ohm per 16 cm length. This determined the dimensions of the coil and the resulting item of equipment.

Attach the asbestos paper (B) to the wooden dowel (A), as indicated, with two or three short nails, and then wrap the paper closely around the dowel. There should be enough paper to make about five layers. Attach the loose end of the asbestos paper to the dowel with two or three more short nails.

Attach the nichrome wire (C) to one end of the dowel by means of a nail, leaving about 7 cm of wire as a free end. Wrap the wire firmly around the dowel to make a coil with a regular 0.5 cm between turns. Do not allow the wire to touch any of the nail heads in the dowel, thus avoiding a "short" between adjacent turns. On reaching the

end of the dowel, attach the wire once more to the dowel with a short nail. Cut off any unnecessary wire, leaving about 7 cm as a free end.

(2) Coil Support

Side View

Make a support for the resistance coil from wood (D) for the base and wood (E) for the two sidepieces. Nail the resistance coil between the sidepieces (E) such that it is 2 cm from the top of, and on the median bisecting, each sidepiece.

Top View

Set the two pieces of plywood (F) in position on top of the support as indicated, but only screw one piece in position for the moment.

(3) Sliding Contact

Bore a hole (diameter 0.3 cm) along the axis of each dowel (G,H). Similarly, drill a hole (0.3 cm diameter) at a distance of 1.5 cm from either end of the brass strip (I).

Side View
(Cross-section)

End View
(Cross-section)

Bend the brass strip (I) into a semicircular shape around the smaller dowel. Insert the bolt (J) through the lower dowel (H) and the end holes in the brass strip (I). Lock the strip in position with a nut (K), and then add washers (L) (no more than 1.2 cm in diameter) to create a spacer between the two dowels of 0.8 cm depth. Slide the larger dowel (G) onto the bolt, and fix it in position with a locking nut (K). Add another nut (K) to serve as a terminal.

Place the sliding contact above the resistance coil so that the fixed top piece of the support fits into the space between the dowels of the sliding contact. Take the second top piece (F) already cut, and set it in position on top of the support so that it holds the sliding contact in position in contact with the resistance coil. Screw the top piece in position on top of the endpieces. If necessary, adjust the position of the resistance coil to insure not only that there is good electrical contact between the sliding contact and the resistance coil, but also that the contact slides smoothly along the length of the coil.

(4) Terminals

Side View

Use the nuts (N) and bolts (M) to make two terminals [see VIII/A2, Component (4)], one at either end of the support top piece, and fasten the free ends of the resistance coil to these terminals.

c. Notes

(i) If the resistor is connected into a circuit by means of the two fixed terminals, a fixed resistance of 25 ohms is added to the circuit. If the terminals used are one fixed terminal and the terminal on the sliding contact, then the resistance added to the circuit may be varied from 25 ohms to almost zero.

(ii) A current passing through the coil will tend to heat it up. A 2-amp current makes the coil fairly hot, and a 3-amp current makes it very hot, but the heating does not affect the performance of the resistor.

C3. Decade Resistor

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	25 cm x 7 cm x 2 cm
(2) Terminals	5	Bolts (B)	0.4 cm diameter, 5 cm long
	10	Nuts (C)	0.4 cm internal diameter
	20	Washers (D)	--
(3) Resistors	1	Resistor (E)	10 ohms, 2.5 watts
	1	Resistor (F)	20 ohms, 1.5 watts
	2	Resistors (G)	30 ohms, 1.0 watt
	1	Copper Wire (H)	#24, 30 cm long
	5	Screws (I)	1.5 cm long
(4) Connectors	4	Brass Strips (J)	7.5 cm x 1.5 cm x 0.05 cm

b. Construction

(1) Base

Use wood (A) for the base. Mark on the top surface the position of the terminals and screws as indicated.

• Terminal Positions

o Screw Positions

(2) Terminals

Drill holes (0.4 cm diameter) in the base (A) in the terminal positions, making sure that the holes are at right angles to the plane of the base. Use a bolt (B), two nuts (C), and two washers (D) to make each terminal.

(3) Resistors

Top View

Insert five screws (I) into the base in the positions indicated. Connect each screw to the nearest terminal with a short length of copper wire (H). Connect radio resistors (E, F, G) (see notes) of 10, 20, 30 and 30 ohms between successive pairs of screws (see notes).

(4) Connectors

Side View

Make four connectors from the brass sheeting (J). Drill a hole (0.7 cm diameter) at a distance of 1.0 cm from each end. Squeezed gently into the shape of an arc, it should be possible to set the connector across two terminals, thus shorting one of the resistors out of the circuit.

c. Notes

(i) The resistance between the main terminals (T) may be any multiple of 10 ohms from 0 to 90, according to the way in which the connectors are placed across the terminals. In the case illustrated the resistance would be 50 ohms.

(ii) If the decade resistor is designed for use with a voltage supply of no more than 5 volts then the 10, 20, and 30 ohm resistors purchased should have ratings of 2.5, 1.5 and 1.0 watts respectively.

R Ohms	V Volts	I Amps	W Watts
10	5	0.50	2.50
20	5	0.25	1.25
30	5	0.17	0.83

Alternatively, if all the resistors purchased were rated at 1 watt, then the voltage placed across the 10, 20 and 30 ohm resistors should never exceed 3.0, 4.5 and 5.5 volts respectively.

R Ohms	W Watts	V = W.R Volts
10	1.0	3.2
20	1.0	4.5
30	1.0	5.5
40	1.0	6.3
50	1.0	7.1
60	1.0	7.6
70	1.0	8.4
80	1.0	8.9
90	1.0	9.5

D. DYNAMO/MOTORS

D1. Simple Motor

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	14 cm x 13 cm x 1.5 cm
	4	Bolts (B)	0.3 cm diameter, 3.0 cm long
	8	Nuts (C)	0.3 cm internal diameter
	2	Coat Hanger Wire (D)	7 cm long, 0.2 cm diameter
(2) Rectangular Coil	1	Roll of Magnet Wire (E)	#26
	1	Coat Hanger Wire (F)	10 cm long, 0.2 cm diameter
	1	Insulating Tape (G)	--
	1	Masking Tape (H)	--
	2	Magnet Wire (I)	#26, 10 cm long
	4	Thumbtacks (J)	--
(3) Electromagnet	1	Soft Iron Bar (K)	17.5 cm x 2.0 cm x 0.3 cm
	1	Roll of Magnet Wire (L)	#26, approximately 100 g
	1	Masking Tape (M)	--
	2	Wood Strips (N)	8 cm x 1.5 cm x 1.0 cm

b. Construction

(1) Base

Top View

Use wood (A) as the base. Use the four bolts (B) and eight nuts (C) to make four terminals [see VIII/A2, Component (4)]. Attach a terminal at each corner of the base, making sure to inset the boltheads into the bottom of the base. Drill two holes (0.2 cm diameter, 1.0 cm deep) into the base to hold the vertical supports.

Make two vertical supports for the coil by twisting the coat hanger wire (D) into the shape indicated. Set the supports vertically upright in the newly drilled holes in the base.

(2) Rectangular Coil

Wind 30 turns of magnet wire (E) around a cardboard form in order to make a coil of internal size 3.5 cm x 1.5 cm. Leave 10 cm of wire free at either end of the coil.

Take the length of straight coat hanger wire (F) and thread it through the middle of the coil to serve as the axle. Wrap the masking tape (H) around the coil and axle to hold the coil firmly in position.

Wrap a length of insulating tape (G) around the axle, adjacent and external to the coil, to create a region of insulation, 1.5 cm long, on the axle (F).

Adjust the ends of the coil wire so that they lie parallel to this insulated portion of the axle, and on either side of it. Cut the parallel wires so that they do not protrude beyond the insulation. Clean the enamel off the wire with sandpaper.

Fasten a thin piece of masking tape (H) around the ends of the coil wire and axle, thus keeping the ends of the coil wire in position. Fit the coil axle into the coil supports on the base. Take the two lengths of copper wire (I), and remove the varnish from the ends. Make one end of each wire into a vertical contact which just touches one of the wire ends from the coil. Hold each wire in position on the base with thumbtacks (J),

and attach the free end of the wire to one of the front terminals as indicated.

(3) Electromagnet

A simple horseshoe magnet, with poles about 4 cm apart, will serve the purpose well. However, if a suitable horseshoe magnet is not available, an electromagnet may readily be made as follows.

Take a soft iron bar (K), and bend it into a horseshoe shape with parallel sides 4.5 cm apart. Take about 100 g of #26 magnet wire (L), and wind a coil on each side of the U-shaped bar. Each coil should be about 4 cm long, and should contain ten layers of wire. The coils should be connected in series to one another, simply by continuing the windings in the same direction around the bar from one coil to the other in a series of widely spaced connecting turns. Cover the final layer of turns with masking tape (M) to hold the coils in position. Connect the free ends of the coils to the rear terminals on the base.

Place two wood strips (N) beneath the electromagnet such that the magnetic poles are either side of, and at the same height as, the middle of the rectangular coil.

c. Notes

(i) With a current of 1 amp through the electromagnet and about 0.7 amp through the rectangular coil, the latter will rotate quite rapidly, thus behaving as a motor. The current required may be readily provided by dry cells.

(ii) With a current of 1 amp through the electromagnet it is possible to generate a current in the rectangular coil by rotating it as rapidly as possible. However, the current generated is extremely small (of the order 0.1 milliamps).

D2. Dynamo/Motor ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	20 cm x 15 cm x 2 cm
(2) Armature	1	Nail (B)	0.7 cm diameter, 15 cm long
	1	Box of Nails (C)	4 cm long
	1	Epoxy Resin (D)	--
	1	Roll of Magnet Wire (E)	#26
(3) Pole Heads	1	Box of Nails (F)	4 cm long
	1	Epoxy Resin (G)	--
	4	High Quality Steel (or Alnico) Bars (H)	7 cm x 1 cm x 1 cm

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(4) Axle Supports	2	Brass Sheets (I)	5.5 cm x 2.0 cm x 0.2 cm
	1	Masking Tape (J)	--
(5) Commutators	1	Brass Tube (K)	1 cm long, 1 cm external diameter, 0.8 cm internal diameter
	1	Epoxy Resin (L)	--
	2	Brass Sheets (M)	5.0 cm x 1.0 cm x 0.1 cm
	1	Brass Tube (N)	1 cm long, 1 cm external diameter, 0.8 cm internal diameter
	2	Brass Sheets (O)	5.0 cm x 1.0 cm x 0.1 cm
	1	Magnet Wire (P)	#26, 15 cm long
(6) Terminals and Electric Wiring	4	Bolts (Q)	0.3 cm diameter, 3.5 cm long
	8	Nuts (R)	0.3 cm internal diameter
	1	Magnet Wire (S)	#26, 40 cm long
(7) Driving Wheel System	1	Wooden Spool (T)	2.5 cm long, 3 cm diameter
	1	Rubber Strip (U)	9.5 cm x 2.5 cm
	1	Wood (V)	12 cm x 5 cm x 4 cm
	1	Wood Disc (W)	15 cm diameter, 1.5 cm thick
	1	Nail (Y)	0.7 cm diameter, 6 cm long
	1	Wooden Spool (Z)	2.5 cm long, 2.5 cm diameter
	1	Screw (AA)	4 cm long
	4	Washers (BB)	0.8 cm internal diameter diameter, approximately

b. Construction

(1) Base

Use the wood (A) as the base.

(2) Armature

Take a wooden block, and drill a vertical hole (0.8 cm diameter) through its center so that it can support steel axle (B). The latter may be a very long nail with the head removed.

Take a sheet of aluminum (13 cm x 4 cm) and with the help of an appropriate series of end projections and holes make it into a cylindrical container (4 cm tall, 4 cm diameter).

Top View

Place the container on the wooden block so that it encircles the axle. Take two wooden rods (4 cm x 2 cm x 1.2 cm) and stand these against opposite walls of the container. Now fill the remaining space in the container with the nails (C) (or similar soft iron material) packed closely side by side and parallel to the axle.

Cover the ends of the nails (not the wood) at both ends of the container with epoxy resin (D), so that when it dries the nails are welded together into a solid soft iron core, penetrated along its axis by the steel axle (B) protruding 4 cm at one end and 7 cm at the other. Remove the aluminum container and the wooden rods. You now have the core of your armature.

Wind as much magnet wire (E) as possible into a coil around the core, making sure that you have about 10 cm of both ends left free on completion of the coil. Temporarily twist the loose ends around the long end of the axle. The resistance of the coil will be approximately 5 ohms.

(3) Pole Heads

Top View

The pole heads are made in very much the same way as the armature core. Two open ended aluminum containers are required this time, one cylindrical (5 cm diameter, 4 cm long) and one a rectangular cube (7 cm x 7 cm x 4 cm). The cylindrical one is placed inside the rectangular one, and the two held apart by two wooden rods (2 cm x 1 cm x 4 cm). Just as when making the armature core, pack the space between the two containers with the nails (F) packed parallel to the axis of the cylindrical

container. Cover the nail ends at both extremities of the containers and the wooden rods. You will now have two pole heads.

Top View

Place the pole heads on the base in the positions illustrated, and attach them firmly to the base with the help of epoxy resin.

Complete the system with four very strong magnets laid parallel to one another (North Pole touching North Pole) across the gap between

the pole heads. The magnet may be purchased, or made (as described under IX/A1 from the steel bars (H).

(4) Axle Supporters

Make two axle supports out of the two brass sheets (I), drilling one hole (0.8 cm diameter) in the upright portion to take the axle, and two holes (0.3 cm diameter) in the base portion to take two screws.

Top View

Slide the supports on to either side of the axle (B), and attach them firmly to the base of the apparatus in the position shown.

Side View

The axle may be held firmly in position by winding masking tape (J) (not scotch tape) around the axle next to, and just outside, the supports. Do this as a last step in constructing this item, however.

(5) Commutators

To make the DC commutator, take a piece of brass tubing (K), and cut it to make two halves.

Take some epoxy resin (L), which is a good insulator, and coat all the inner surfaces of the two halves with resin about 0.1 cm thick.

Rotate the armature coil until it is in a vertical plane, and then attach the two split halves to the axle so that the split between the halves is in a horizontal plane. If the epoxy resin is thick enough, it will not only attach the split halves firmly to the axle, but will also insulate the two halves from one another, and from the axle itself.

Take the two loose wires from the armature coil and, after cleaning the ends with sandpaper, solder one to one split half and the other to the other split half.

Cut two identical contacts out of the thin brass sheets (M) as shown. Attach these to the base of the apparatus with screws, so that they are in spring contact with opposite sides of the split halves.

The DC commutator is now complete.

To make the AC commutator, cut two identical rings from the brass tubing (N).

Temporarily remove the axle support and slide the two rings onto the axle. Coat a length of axle (0.5 cm long) with epoxy resin about 0.1 cm thick and slide ring "A" into position over this. The epoxy

resin should be such as to insulate the ring from the axle as well as to hold it firmly in position.

Ring "B" is soldered to the axle about 0.5 cm from ring A. Solder insures good electrical contact between the ring and axle. Two contacts, identical to those described above, should be cut from brass (O), and attached to the base so that each is in spring contact with one of the rings.

Connect ring "B" electrically to one of the split halves by soldering a very short length of magnet wire (P) from ring "B" to the axle and another piece from one split half to the axle. Don't forget to clean the ends of the magnet wire with sandpaper prior to soldering.

Connect ring "A" electrically to the other split half by soldering a length of magnet wire (P) from one to the other.

The AC commutator is now complete.

(6) Terminals and Electric Wiring

Side View
(Cross-section)

Fahnstock Clip

Top view

Drill four holes through the base to take four terminals, two to serve as an AC outlet and two as a DC outlet.

Make each terminal as described under VIII/A2, Component (4). Each terminal requires a bolt (Q), and two nuts (R).

It is of course very nice to have fairly large nuts which can be easily adjusted with the fingers. Such nuts are probably best made on a metal lathe. The nuts might both be 1 cm in diameter, with the thickness of the terminal nut being 0.5 cm and that of the locking nut 0.2 cm.

In some localities it is cheaper to purchase terminals on the local market. Check the availability of such items as Fahnstock clips which can replace the above. Take some magnet wire (S), clean the ends with sandpaper, and then connect the terminals to the contacts as illustrated, fastening the wire beneath the locking nut on the terminal.

(7) Driving Wheel System

Top View

Take the wooden spool (T) and fill the central hole with wood putty. When the latter is perfectly dry, drill a new hole (0.7 cm diameter) along its axis so that it will just fit on the armature axle. A rubber strip (U) may be cut from an old car inner tube. Nail it around the perimeter of the spool. Temporarily remove the appropriate axle support, and attach the spool firmly to the axle with epoxy resin. Use wood (V) as a support for the driving wheel, locating it on the base in the position shown. Cut a slight inset (0.2 cm) into the base to hold the bottom of the support (V) firmly, and put some wood cement in the inset. Fasten the support firmly in position with the help of two wood screws passing through the base of the apparatus.

Use the wooden disc (W) to serve as the driving wheel. The rubber strip (X), cut from an old car inner tube, should be nailed around the perimeter of the disc. Drill a hole (0.8 cm diameter) through the center of the disc, and pass a nail (Y) through it to serve as a pivot.

Side View
(Cross-section)

Drill a hole along the axis of the spool (Z) so that the spool fits loosely on the screw (AA), but cannot slip over the screw-head. Screw the spool onto the driving wheel about 4 cm from the perimeter. Put washers (BB) either side of the spool to permit it freedom of motion. You now have a handle for the driving wheel.

Washers (BB) should be similarly placed on the pivot, either side of the driving wheel.

Side View
(Cross-section)

Finally, hold the driving wheel tight against the axle spool, and use the pivot (Y) to mark the best position to locate it permanently in the support. This will be at a height of approximately 10 cm on the support. Drill a horizontal hole (diameter 0.7 cm) into the support, and fix the pivot firmly in the hole with epoxy resin.

Your dynamo/motor is now ready for operation.

c. Notes

(i) The Dynamo/Motor was tested out with two Nuffield horseshoe magnets (Nuffield Physics Item 50/2) across the pole heads; these appear to produce a fairly standard field, whereas locally produced ones vary considerably in strength, depending on the quality of steel or alnico used. The driving wheel was turned at as rapid, but constant, a speed as possible, and was noted to be turned at

4.5 to 5.0 revolutions per second on the average. Under these conditions the following observations were made:

The dynamo was found to produce up to 1.1 volts DC and 1.2 volts AC on open circuit.

Connected in series with a small bulb (1.1 volts, 5 ohms) the dynamo produced a DC current of 0.11 amp at 0.25 volts, and an AC current of 0.13 amp at 0.5 volts. On both occasions the bulb was noted to flicker faintly.

(ii) With the driving wheel disconnected, it was noted that a voltage of 1.4 volts, producing 0.2 amp, was capable of driving the motor.

IX. ELECTROMAGNETISM APPARATUS

A. ELECTROMAGNETISM APPARATUS

The apparatus in this group is primarily concerned with the creation of magnetic fields in various forms.

A. ELECTROMAGNETISM APPARATUS

A1. Magnetizing Coil and Magnets ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	15 cm x 15 cm x 2 cm
(2) Spool	1	Wooden Dowel (B)	3 cm diameter, 8 cm long
(3) Endpieces	2	Wooden Strips (C)	8 cm x 8 cm x 0.5 cm
(4) Coil	1	Roll of Magnet Wire (D)	#22, 1 kg
	1	Switch (E)	220 volts
	1	Double Electrical Cord (F)	#20, 200 cm long
	1	Two Pin Plug	220 volts
	1	Insulating Tape (H)	--

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b. Construction

(1) Base

Use wood (A) as the base.

(2) Spool

Drill a hole (2 cm diameter) along the axis of the wooden dowel (B) to make an appropriate spool.

(3) Endpieces

Drill a hole (2 cm diameter) in the middle of each wood strip (C) and attach the strips to either end of the spool with wood cement.

(4) Coil

Wind all of magnet wire (D) on to the spool taking care to leave about 25 cm of free wire at either end of the coil for appropriate connections. The winding of the coil may be facilitated by the use of a brace as follows.

Hammer two large nails (15 cm long) into the side of a bench so that they protrude horizontally some 50 cm apart. Place the spool to be wound on one of the nails. Fasten the first turn of magnet wire around the spool in such a way that it will not slip on turning the spool. Then get your partner to hold the wire taut over the second nail so that it may be wound under tension.

Attach a short shaft (2 cm long, 1 cm diameter) to the center of a circular disc (7 cm diameter, 0.5 cm thick) by means of a screw. Hammer three nails through the perimeter of the disc and drill three corresponding holes in the endpiece of the spool to take the protruding nails. Clamp the jaws of the brace firmly on to the shaft. Lock the disc and spool together by means of the disc nails, and then begin to wind the coil by turning the brace.

Drill a small hole in each endpiece and loop the wire ends through these holes to prevent unwinding of the coil.

Make two insets (8 cm long, 0.5 cm wide, 0.2 cm deep) in appropriate positions on the base to hold the endpieces. Fix the endpieces firmly in the insets with wood cement.

Attach switch (E) to the base, and connect one of the loose wires from the coil to the switch. Insert a screw into the base as indicated, and attach the other wire from the coil.to the newly inserted screw. Take

the double electrical cord (F) with two pin plug (G) attached, and connect one wire to the screw, and the other wire to the switch.

Since the coil and wires will carry a high voltage (220 volts), it is important that all wiring should be covered with insulating tape (H). Cover the coil, the wire and the screw with the tape.

c. Notes

(i) To magnetize an item, place a suitable steel specimen in the center of the coil. Switch the current quickly on and off. The specimen will be magnetized on removal from the coil.

Ticonal is an ideal alloy for making magnets, but is rarely available on local markets. High quality tool steel is a good second best, and is generally found in good quality tools (chisels, screwdrivers, drill bits, etc.), as well as domestic items such as razor blades and sewing needles.

Unfortunately, the "high grade steel" sold on many local markets tends to to be of poor quality, and does not retain magnetism well. However, if the steel is heated to red heat in any oxy-actylene flame, and then quenched in cold water, it tends to be hardened, and hold magnetism somewhat better. (It should be noted that "steel rods" used in construction work for reinforcing concrete are made of soft iron, and cannot be permanently magnetized.

This magnetizing coil is designed for use with a 220 volt mains supply, and is capable of producing extremely strong magnets. It would also work with a 110 volt supply, but the magnetism induced in a given specimen would be weaker than with a 220 volt supply. The magnetizing coil should never be switched on and left on, as it would overheat and burn out. It is designed for usage over very short periods of time (2 or 3 seconds only).

To demagnetize a specimen, place tne magnet inside the coil and hold its end very firmly. Switch on the current, and remove the specimen from the coil maintaining a firm grip on it. The current is not switched off until the specimen is completely out of the coil.

A2. Multipurpose Coil with Cores

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Coil	1	Dowel (A)	1.2 cm diameter, 3 cm long
	2	Wood Strips (B)	3 cm x 2 cm x 0.5 cm
	1	Roll of Magnet Wire (C)	#22
	1	Masking Tape (D)	--
	2	Brass Bolts (E)	0.3 cm diameter, 1.5 cm long
	4	Nuts (F)	0.3 cm internal diameter
(2) Core	1	Bolt (G)	0.4 cm diameter, 4.5 cm long
	1	Soft Iron Plate (H)	3 cm x 2 cm x 0.3 cm

b. Construction

(1) Coil

The size of the coil is not critical, but it does affect the spacing and size of components used on the Magnetic Field Apparatus (IX/A4) and Moving Coil Galvanometer (X/C2).

Drill a hole (0.6 cm diameter) along the axis of the dowel (A).

Drill similar holes in the two wood strips (B), at a distance of 1.0 cm from the ends, so that when the strips are attached to either end of the wooden dowel (A) they serve as endpieces with a common axial hole. Cut off the top corners of the end-pieces, and smooth them down with sandpaper.

Wind ten layers of magnet wire (C) on to the dowel, leaving about 10 cm of wire free at either end of the coil. Cover the final layer of wire with masking tape (D) to hold the coil in position.

Use bolts (E) and nuts (F) to make two terminals as described under VIII/A2, Component (4), and attach them to one endpiece as indicated.

Clean the ends of the two wires from the coil, and fasten them under the locking nuts of the respective terminals. Make sure that it is possible to see the

way in which the wire from each terminal begins to wind around the coil, for this makes it possible to determine the direction of the current around the coil, and hence the direction of the magnetic field produced.

(2) Core

Drill an inset (0.4 cm deep, 1.0 cm diameter) over the hole in the endpiece which contains the terminals. Insert bolt (G) so that the bolthead sits snugly in the inset.

Drill a hole (0.4 cm diameter) through the center of the iron plate (H). Make a thread (0.4 cm diameter) in the hole, and attach the iron plate to the bolt (G) by means of the threaded hole.

c. Notes

(i) The multipurpose coil may be used in a wide range of experiments to produce magnetic fields. It may also be used in instruments [e.g., the Magnetic Field Apparatus (IX/A4) and the Moving Coil Galvanometer (X/C2)] where a fixed magnetic field is required.

A3. Magnetic Field Apparatus ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	10 cm x 7 cm x 1 cm
	1	Wood (B)	10 cm x 4 cm x 2 cm
	2	Wood Screws (C)	2 cm long
	2	Brass Bolts (D)	0.3 cm diameter, 2 cm long
	4	Nuts (E)	0.3 cm internal diameter
	1	Bolt (F)	0.2 cm diameter, 2 cm long
	1	Nut (G)	0.2 cm internal diameter
	2	Thumbtacks (H)	--

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(2) Field System	2	Brass Rods (I)	0.4 cm diameter, 5 cm long
	2	Nuts (J)	0.3 cm internal diameter
	2	Magnet Wires (K)	#22, 8 cm long
	1	Aluminum Rod (L)	0.3 cm diameter, 4 cm long
	1	Horseshoe Magnet (M)	--

b. Construction

(1) Support

Use wood (A) as the base.

Attach wood (B) vertically to the base with two wood screws (C) passed through the base (4 cm from one end). Use wood cement to insure a firm joint between the upright and base.

Use the bolts (D) and nuts (E) to make two terminals, as described under VIII/A2, Component (4), and attach these to the base (A) just behind the upright (B).

Drill a hole (0.3 cm diameter) through the base to take bolt (F). Inset nut (G) over the hole by striking it into position with a hammer. Thread the bolt through the nut thus producing an adjustment screw for levelling the base. At opposite corners on the other side of the base, insert two thumbtacks (H) beneath the base, so that the latter sits on three points, the adjustment screw and two thumbtacks.

A4. Magnetic Field Apparatus with Multipurpose Coils ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basic Apparatus	1	Magnetic Field Apparatus (A)	IX/A3, No magnet required
(2) Multipurpose Coils	2	Multipurpose Coils with Cores (B)	IX/A2
(3) Coil Holders	2	Brass Sheets (C)	2 cm x 2 cm x 0.02 cm
	4	Screws (D)	Approximately 0.6 cm long
	4	Brass Sheets (E)	3 cm x 0.8 cm x 0.05 cm

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	4	Screws (F)	Approximately 0.6 cm long
(4) Terminals	2	Brass Bolts (G)	0.3 cm diameter, 2 cm long
	4	Nuts (H)	0.3 cm internal diameter
	1	Magnet Wire (I)	#24

b. Construction

(1) Basic Apparatus

Make the Magnetic Field Apparatus (A) as described under IX/A3. A horseshoe magnet is not required, and the magnetic field is produced by means of the additional components described below.

(2) Multipurpose Coils

Make two Multipurpose Coils (B), complete with pole heads, as described under IX/A2. Cut a horizontal groove in the front endpiece of each (just beneath the pole heads) to insure a good grip for the coil holders.

(3) Coil Holders

Bend the two brass sheets (C) into spring holders as indicated. Drill two screw holes in the center portion.

Cut a slot (0.7 cm x 0.3 cm) in the end of each of the brass sheets (E) and drill a screw hole in the other end, thus producing four clip holders.

Bend two of the holders at right angles to make L-shaped clips as follows.

Measure the distance from the center of the coil terminal to the upright. Let's say this is 1 cm. Then the clips must be bent at right angles at 1.3 cm from the slotted end. Fit the slotted end of each clip holder under the locking nut of a terminal on the lower coil, and use screws (F) to attach the clips to the upright.

Use screws (D) to attach the spring holders horizontally to the upright of the apparatus, 1 cm above, and 1 cm below, the horizontal rods. Clip the multipurpose coils temporarily in the spring holders, and mark out the positions of the free endpieces of the coils.

Cut the top off the upright, so that it is level with the top of the upper coil. Take two clips, and fasten the slotted end of each under the locking nut of a terminal on the top end of the coil. Then holding the coil close to the upright, attach the

(4) Terminals

clips to it with small screws (F).

Use bolts (G) and nuts (H) to make two terminals, as described under VIII/A2, Component (4). Attach them to the front of the base. Finally connect the terminals and coil holders by magnet wire (I) so that electrical connections exist between points a to a, b to b, and c to c (see diagram), thus insuring that current will flow through the multipurpose coils in the same direction once the terminals at the front of the base are connected into a circuit.

c. Notes

(i) The apparatus may be used to study the relationship between the force exerted on a current carrying conductor and the magnetic field surrounding the conductor. For this purpose a suitable magnetic field may be created by connecting two dry cells (1.5 volts each) and a torch bulb in series with the multipurpose coils. A strong current may be passed through the lightweight roller by momentarily connecting three dry cells in series with the terminals leading to the horizontal rods. Under such conditions the roller will be propelled along the rods.

X. GALVANOMETERS

A. ELEMENTARY GALVANOMETERS

These are extremely simple instruments which illustrate the elementary principles of galvanometry. They may be used as simple measuring devices, but are not designed for accuracy of measurement.

B. FUNCTIONAL TANGENT GALVANOMETERS

These instruments are probably the most suitable for general use in the school laboratory. They are simple to make and more durable than moving coil galvanometers. In addition, they are surprisingly sensitive, and with the help of shunts may be used for a multiple range of measurements.

C. FUNCTIONAL MOVING COIL GALVANOMETERS

These instruments are quite sensitive, and with the help of shunts may be used for a multiple range of measurements.

A. ELEMENTARY GALVANOMETERS

A1. Elementary Tangent Galvanometer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	7 cm x 7 cm x 1 cm
(2) Coil	1	Magnet Wire (B)	#26, 400 cm long
	--	Masking Tape (C)	--
	1	Screw (D)	1 cm long
	1	Washer (E)	--
(3) Magnetic Needle	1	Needle (F)	0.1 cm diameter
	1	Cotton Thread (G)	5 cm long
(4) Terminals	2	Bolts (H)	0.3 cm diameter, 2.5 cm long
	4	Nuts (I)	0.3 cm internal diameter

b. Construction

(1) Base

Make the base out of wood (A).

(2) Coil

Wind 20 turns of the magnet wire (B) around a cardboard form to make a rectangular coil (5 cm x 3 cm), leaving about 5 cm of free wire at either end of the coil.

Remove the coil from the form, and wrap sufficient masking tape (C) around the coil to insure that it maintains its shape. Then separate the windings slightly on the bottom side of the coil, mount the coil on the base with the help of a washer (E) and a screw (D) passed through the separated windings.

(3) Magnetic Needle

Magnetize a needle (F) with the help of a magnetizing coil (IX/A1). Cut off about 4 cm of the needle, and suspend it horizontally at the middle of the coil by means of a cotton thread (G) attached to the top of the coil.

(4) Terminals

Use the bolts (H) and nuts (I) to make two terminals in the base as described under item VIII/A2, Component (4). Clean

the ends of the coil wire with sandpaper, and fasten the wires to the terminals.

c. Notes

(i) Prior to using this apparatus it should be set so that the needle is suspended in the plane of the coil. A current passed through the coil will cause the needle to be deflected away from the plane of the coil, the deflection depending on the magnitude of the current carried by the coil. The apparatus simply illustrates the principle of the tangent galvanometer, and is too crude for specific measurements.

A2. Repulsion Type Galvanometer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	10 cm x 10 cm x 1 cm
	2	Bolts (B)	0.3 cm diameter, 2.5 cm long
	4	Nuts (C)	0.3 cm internal diameter
(2) Coil	1	Cardboard Sheet (D)	20 cm x 3.5 cm
	--	Masking Tape (E)	--
	1	Roll of Magnet Wire (F)	#26, (diameter 0.05 cm), 30 meters long
	1	Aluminum Sheet (G)	7 cm x 4 cm x 0.02 cm
	4	Screws (H)	1 cm long
(3) Repulsion Vane Assembly	1	Galvanized Iron Sheet (I)	7 cm x 3.5 cm x 0.02 cm
	1	Galvanized Iron Sheet (J)	4.3 cm x 2.5 cm x 0.02 cm
	1	Needle (K)	8 cm long, 0.1 cm diameter
	--	Masking Tape (L)	--

1	Soda Straw (M)	--
1	Cardboard Sheet (N)	12 cm x 12 cm

b. Construction

(1) Base

Top View

Make two terminals from bolts (B) and nuts (C) [as described under VIII/A2, Component (4)] and attach them at about 2 cm from the edge of the wood (A). The boltheads of the terminals should be countersunk into the base, so that the latter sits flat on any horizontal surface.

(2) Coil

Cut a piece of wood (5 cm x 5 cm x 5 cm) to serve as a winding block for the coil. Use a razor blade to score parallel lines on the cardboard (D) at 5 cm intervals so that it may be readily bent into the shape of the wooden block.

Wrap the cardboard loosely around the block fastening the two loose edges together with masking tape (E).

Wind approximately 150 turns of the magnet wire (F) onto the cardboard form. This will take three layers of turns. After winding the turns, remove the cardboard holder (and turns) from the winding block, and cover the turns with masking tape (E) to hold the wire in position. Make sure that about 10 cm of wire is free at both ends of the coil.

Drill two holes (diameter 0.2 cm) at either end of the aluminum sheet (G). Set the coil in a vertical plane on the base, and strap it in position with the help of the aluminum sheet (G) and four screws (H). Bare the ends of the wire, and attach them to the terminals on the base.

(3) Repulsion Vane Assembly

Two vanes are required, one fixed and one free swinging. The fixed vane may be cut from a sheet of galvanized iron (I) according to the dimensions indicated. The cut sheet resembles a vertical cross. Drill a hole (0.2 cm diameter) in the top edge of each of the horizontal portions of the cross (see illustration). Then bend the sheet at right angles along the lines indicated.

The completed vane may then be fixed vertically in position within the coil by wrapping masking tape (L) around the top of the coil, covering the horizontal portion of the fixed vane in the process.

The free swinging vane is made from the other sheet of galvanized iron (J) and suspended from the middle of the needle (K) by wrapping a piece of masking tape (L) over the end of the vane. Suspend the vane from the projections on the fixed vane.

Back View

Make a pointer from the straw (M), and pivot it on the needle (K) at about 2 cm from the end of the straw. Make the scale from the cardboard (N), bending the bottom of the scale at right angles to form a horizontal flap. Use masking tape to attach the flap (and hence the scale) to the top of the coil.

c. Notes

(i) The galvanometer may be calibrated by placing it in series with an ammeter (0 - 5 amps), a voltage supply (dry cells, battery, etc.) and a variable resistance.

(ii) The resulting scale will be nonuniform, the separation of points on the scale increasing with increasing amperage. The range of the scale for this

particular design will be approximately 0 to 3 amps (DC).

(iii) The galvanometer will measure both DC and AC current equally well, since the repulsion of the vanes is independent of the direction of the current in the coil.

(iv) The resistance of the galvanometer is approximately 2.5 ohms. The current existing in a circuit will therefore be affected in general by the addition of the galvanometer to the circuit.

A3. Hot Wire Ammeter

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	20 cm x 12 cm x 2 cm
	1	Wood (B)	12 cm x 12 cm x 2 cm
	2	Screws (C)	3 cm long
	2	Bolts (D)	0.3 cm diameter, 3.5 cm long
	4	Nuts (E)	0.3 cm internal diameter
(2) Pulley System	2	Aluminum Sheets (F)	5 cm x 2 cm x 0.05 cm
	4	Screws (G)	1 cm long
	1	Needle (H)	5 cm long, 0.1 cm diameter
	1	Wooden Dowel (I)	0.5 cm diameter, 1 cm long
	1	Soda Straw (J)	--
	1	Cardboard Sheet (K)	12 cm x 6 cm
(3) Wiring	2	Eye Screws (L)	--
	3	Wood Screws (M)	1.5 cm long
	2	Washers (N)	--
	1	Nichrome Wire (O)	#30, 22 cm long, 0.02 cm diameter

	1	Copper Wire (P)	#24, 50 cm long
(4) Spring System	1	Wood (Q)	2 cm x 2 cm x 1 cm
	1	Steel Wire (R)	#16, diameter 0.12 cm, length 12 cm
	1	Screw (S)	1 cm long
	1	Thread (T)	10 cm long
	1	Paper Clip (U)	Approximately 1 cm long

b. Construction

(1) Support

Attach the vertical component (A) to the middle of the base (B) with the help of screws (C) and wood cement.

Use the bolts (D) and nuts (E) to make two terminals [as described under VIII/A2, Component (4)] and attach these to the front of the base. The boltheads of the terminals should be countersunk into the bottom of the base (B) so that the latter sits flat on any horizontal surface.

(2) Pulley System

Drill a hole (diameter 0.5 cm) through the exact middle of the vertical component (A) of the support. Drill a hole (diameter 0.2 cm) through the center of each of the aluminum plates (F) to serve as pivot holes for the pointer. Drill two holes (diameter 0.2 cm) in diagonally opposite corners of each plate, so that the latter may be screwed onto either side of the support over the centrally drilled hole. The holes in the plates should be at the same height on both sides of

Cross Section

the support, so that the needle (H) may be pivoted horizontally through the holes.

Use a file and sandpaper to make a groove in the wood dowel (I) forming a pulley, thus preventing string from slipping off it. Drill a small hole in the end of the pulley (I) so that it may be slipped onto the end of the needle (H), and fix it firmly in position with the help of glue.

Make a pointer from the soda straw (J) and attach it to the needle about 2 cm from the end of the straw.

Cut a semicircular scale (diameter 12 cm) out of cardboard (K), and glue it to the vertical support behind the pointer.

(3) Wiring

Back View

Fix two eye screws (L) into the rear right-hand side of the support. About 2 cm to the left of each eye screw fix a small wood screw (M) and a washer (N).

Connect the nichrome wire (O) from one wood screw, through both eye screws, to the other wood screw. The length of the wire should be adjusted so that it needs to be pulled about 0.5 cm from the vertical, at its center point, in order to make it completely taut.

Drill two holes in the vertical component of the support to carry electrical wire from the rear of the support to the front. Make one hole (0.2 cm diameter) through the support about 1 cm beneath the bottom wood screw and a second hole at the same height, but on the left side of the support. Connect a length of copper wire (P) from the lower wood screw, through the nearest hole in the support, to the nearest terminal at the front of the base. Connect a second length of wire (P) from the upper wood screw, through the second drill hole, to the remaining terminal. It is convenient to keep the second copper wire away from the middle of the support and the pulley system, with the help of a third wood screw (M).

(4) Spring System

Back View

Attach the small wood block (Q) to the rear of the support at the top left-hand corner. Insert a screw (S) into the block and fasten the end of a length of steel wire (R) between the screw and block so that the wire is held rigidly in a vertical position, thus serving as a spring.

Attach the thread (T) at one end to the middle of the hot wire (O) with the help of a small paper clip (U). Wrap the thread around the pulley (I) once, and then tie the free end onto the spring wire (R). In order to do this make a small kink in the steel wire at the point of attachment of the thread, thus preventing the latter from slipping, and during the tying of the thread, make sure that the spring wire is pulled towards the hot wire. This insures that the thread is always under tension, and that the pulley (and hence pointer) responds readily to any movement of the hot wire.

c. Notes

(i) The galvanometer may be calibrated by placing it in series with an ammeter (0 - 5 amps), a voltage supply (dry cells, battery, etc.) and a variable resistance.

(ii) The resulting scale will be nonuniform, the separation of points on the scale increasing with increasing amperage. The range of the scale for this particular design will be approximately 0 to 1.5 amps (DC).

(iii) The galvanometer will measure both DC and AC current equally well, since the extension of the hot wire (and hence the movement of the pointer) is dependent on the heating of the wire, which in turn is proportional to the square of the current passing through the wire.

(iv) The resistance of this galvanometer is approximately 4.5 ohms.

A4. Current Balance

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	22 cm x 5 cm x 2 cm
	1	Wood Strip (B)	6 cm x 2 cm x 0.5 cm
	1	Aluminum Sheet (C)	10 cm x 2 cm x 0.05 cm
	1	Screw (D)	1 cm long
(2) Balance Arm	1	Needle (E)	4 cm long, 0.1 cm diameter
	1	Soda Straw (F)	21 cm long, approximately
	1	Nail (G)	0.4 cm diameter
	1	Magnet Wire (H)	#30, 10 cm long
	--	Masking Tape (I)	--
	2	Pins (J)	--
(3) Coil	1	Sheet of Paper (K)	10 cm x 2 cm
	.1	Cardboard Sheet (L)	2 cm x 2 cm
	1	Magnet Wire (M)	#22, 400 cm long
	--	Masking Tape (N)	--
	2	Bolts (O)	0.3 cm diameter, 3.5 cm long
	4	Nuts (P)	0.3 cm internal diameter

b. Construction

(1) Base

Fasten an upright piece of wood (B) to the rear of the base (A), and to one side. Make a pivot support from the sheet of aluminum (C). Drill a hole (diameter 0.2 cm) in the middle of the horizontal portion of the support, and attach it to the base with the screw (D).

Pivot Support (C)

Using a small file cut a shallow, smooth notch in the top of each side of the support to hold a subsequent needle pivot in position.

(2) Balance Arm

Insert the needle (E) through the top edge of soda straw (F) at a distance of 7 cm from one end. Balance the straw on the support.

Cut two lengths from the nail (G), one 1.0 cm long and one 2.0 cm long. Attach a three centimeter-long loop of the magnet wire (H) to the end of each nail with the help of a strip of masking tape (I). Hang

the short nail at the end of the short arm of the straw, and hang the long nail at an appropriate point on the other side of the pivot to serve as a counter-balance. A drop of glue (or a small piece of masking tape) can insure that the loops do not slip along the straw.

With the straw balanced horizontally note the corresponding point on the upright (B). Insert two pins (J) horizontally into the upright, one pin 0.5 cm above the top surface of the balanced straw, and the other 0.5 cm below the bottom surface, thus restricting the motion of the end of the straw to about 1 cm.

Set a length of magnet wire (M) on the straw to serve as a rider (see notes).

Wrap the paper (K) around a wooden dowel (1.0 cm diameter) to make a paper cylinder. Secure the loose ends of the paper with masking tape (N).

Cut two washers (internal diameter 1.0 cm, external diameter 2.0 cm) from the sheets of cardboard (L). Attach the washers to the ends of the paper cylinder with glue.

Wind the magnet wire (M) onto the paper cylinder to make a coil. Leave 10 cm of wire free at either end. Cover the last layer of wire with masking tape (N) to hold the coil in position. Remove the coil from the dowel, and mount it on the end of the base with glue in such a way that the axis of the coil is directly beneath the nail suspended from the end of the straw balance arm.

Drill two holes (diameter 0.3 cm) in the base at any convenient point close to the coil, and make two terminals from the nuts (P) and bolts (O) as described under VIII/A2, Component (4). Fit the terminals in the two holes, and connect the wires from the coil to the terminals.

c. Notes

(i) The galvanometer may be calibrated by placing it in series with an ammeter, a voltage supply and a variable resistance, noting the position of the rider each time the straw balance arm is balanced and noting simultaneously the corresponding current through the coil.

(ii) A whole range of different scales may be produced simply by changing the mass of the rider on the balance arm. One such scale is illustrated below when the rider used was a 25 cm length of #26 magnet wire coiled into a loop, approximately 1 cm diameter.

(iii) The resultant scale on the straw is linear. In other words, doubling the current passing through the coil doubles the force exerted by the coil on the nail, and the distance between the rider and pivot must be doubled to reestablish the balance of the straw.

(iv) The galvanometer will measure AC and DC currents equally well since the direction of the attraction exerted by the coil is not dependent on the direction of the current through the coil.

(v) The resistance of the galvanometer is approximately 0.1 ohms.

A5. Elementary Moving Coil Galvonometer

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	14 cm x 13 cm x 1.5 cm
	2	Bolts (B)	0.3 cm diameter, 3.0 cm long
	4	Nuts (C)	0.3 cm internal diameter
	2	Coat Hanger Wire (D)	7 cm long, 0.2 cm diameter
(2) Moving Coil	1	Roll of Magnet Wire (E)	#26
	1	Coat Hanger Wire (F)	10 cm long, 0.2 cm diameter
	1	Masking Tape (G)	--
	2	Thumbtacks (H)	--
(3) Magnet	1	Horseshoe Magnet (I)	--
	2	Wood Strips (J)	Approximately 8 cm x 1.5 cm x 1.0 cm
(4) Scale	1	Straw (K)	6 cm long
	1	Cardboard Sheet (L)	10 cm x 10 cm

b. Construction

(1) Base

Wood (A)

Make two terminals [see VIII/A2, Component (4)] from the nuts (C) and bolts (B), making sure to inset the boltheads into the bottom of the wood (A). Drill two holes (0.2 cm diameter, 1.0 cm deep) into the base to hold the vertical supports.

Side View

(Cross-section)

Make two vertical supports for the coil by twisting the coat hanger wire (D) into the shape indicated. Set the supports vertically upright in the newly drilled holes in the base.

(2) Moving Coil

Wind 30 turns of magnet wire (E) around a cardboard form in order to make a coil of internal size 3.5 cm x 1.5 cm. Leave 100 cm of wire free at either end of the coil.

Thread the wire (F) through the middle of the coil to serve as the axle for the coil. Wrap masking tape (G) around the coil and axle to hold the coil firmly in position.

Fit the coil (F) into the coil supports (D) on the base. Wind the 100 cm of magnet wire (E) at either end of the coil into a spring, and attach the wire, just beneath each spring, to the base with the help of a thumb-tack (H). Each spring should contain about eight turns and be about 3 cm in diameter.

Top View

(The sensitivity of the moving coil increases with increasing number of turns and increasing diameter of the spring.) Connect the wire from the springs to the terminals on the base.

Prevent slipping of the axle on the supports by wrapping masking tape (G) around the axle either side of one of the supports.

(3) Magnet

Procure a horeseshoe magnet (I) with pole heads at least 4 cm apart, and place it as shown around the coil. Make two wooden strips (J) which, when placed under the magnet, will bring the pole heads up to the same height as the coil. The ends of the magnet should be located opposite the middle of the coil.

Top View

Magnet (I)

Coil

Wood Strips (J)

(4) Scale

Take the straw (K) and, after piercing it 1 cm from one end, fit it on the end of the axle. A little glue will fix it firmly in position. Cut a suitable scale out of cardboard (L), and attach it to the base, so that it stands just behind the pointer.

c. Notes

(i) The galvanometer may be calibrated by placing it in series with an ammeter, a voltage source and a variable resistance. The sensitivity of the galvanometer will depend very much on the strength of the horseshoe magnet used.

(ii) The galvanometer will measure DC current, but not AC.

(iii) If a suitable horseshoe magnet is not available, an electromagnet may readily be made. To do this, take a soft iron bar (17.5 cm x 2.0 cm x 0.3 cm), and bend it into a horseshoe shape as indicated. Take about 100 g of #26 magnet wire, and wind a coil on each side of the U-shaped bar. Each coil should be about 4 cm long, and should contain ten layers of wire. The coils should be connected in series to one another, simply by continuing the windings in the same direction around the bar from one coil to the other in a series of widely spaced connecting turns. The coils may be held in position by means of masking tape. If the coil is connected in series into a separate electrical circuit, it may be used in precisely the same way as the former horseshoe magnet.

(iv) With a current of 0.5 amps through the electromagnet coils, a 2-amp current through the moving coil produced a deflection of approximately 30°. When the current through the electromagnet was increased to 1.0 amp, the deflection, due to a 3-amp current through the moving coil, increased to 45°.

Electiomagnet Current of Lamp

B. FUNCTIONAL TANGENT GALVANOMETERS

B1. Tangent Galvanometer ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Box Support	1	Wooden Base (A)	12 cm x 6 cm x 1 cm
	2	Wooden Sides (B)	6 cm x 2 cm x 1 cm
	1	Wooden Platform (C)	12 cm x 6 cm x 1 cm
	18	Small Wood Screws (D)	1.5 cm long
(2) Coil	1	Roll of Magnet Wire (E)	#24
	--	Varnish (F)	--
(3) Terminals	2	Brass Bolts (G)	0.3 cm diameter, 2 cm long
	4	Nuts (H)	0.3 cm internal diameter
(4) Compass	1	Wood Disc (I)	2.5 cm diameter, 0.3 cm thick
	3	Needles (J)	0.1 cm diameter
	1	Brass Rod (K)	0.5 cm diameter, 0.5 cm long

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b. Construction

(1) Support

Make a four-sided wooden support from the wooden base (A), wooden sides (B) and platform (C). Fasten the base and sides together with small screws (D) and wood cement, but do not put the platform in position yet.

Drill an inset (2.5 cm diameter, 0.2 cm deep) into the middle of the platform, and two holes (1 cm diameter) right through the platform to take the coil. Cut the platform into two equal halves, fastening one half only in position with small screws and wood cement.

(2) Coil

To make the coil a simple winding device is desirable. This may be made from a block of wood (5 cm x 5 cm x 1 cm) and two cardboard sides (8 cm x 8 cm x 0.5 cm). Drill a hole through the middle of the block and sides and hold the parts together with a bolt and wing nut.

Wind 100 turns of magnet wire (E) onto the block, layer by layer, adding a coat of varnish (F) to each layer to hold the turns together. Make sure that about 20 cm of both ends of the

wire are left free to make appropriate connections.

When the varnish is dry remove the coil from the block (simply by releasing the sides) and sit the coil vertically in the support.

Attach the second half of the platform with small wood screws and wood cement.

(3) Terminals

Use bolts (G) and nuts (H) to make two terminals as described under VIII/A2, Component (4). Fix one on either side of the support, and attach the two wires from the coil to the terminals. Don't forget to clean the ends of the wire with sandpaper.

(4) Compass

Use the wood disc (I) as the base of the compass. Alternatively, a cork disc would serve equally well, although less durable.

Cut a 1 cm length off the pointed end of a needle (J). Drill a small hole (0.1 cm diameter) in the middle of the base and set the needle in the hole with epoxy resin so that it stands vertically, pointed end uppermost.

Holding rod (K) firmly in a clamp, drill a hole (0.3 cm diameter) 0.3 cm deep along the axis. You now have a suitable cap to sit on the pivot.

Cut 2 cm lengths off the two remaining needles (J). Determine the center of gravity of each by balancing the needles over another needle. Mark in the position of the center of gravity of each of the two needles.

Hold the needles parallel to one another and drop some solder on the base of the cap. Immediately attach the needles (at their centers of gravity) to the cap by placing them in the still molten solder.

Finally, place the cap and needles inside a magnetizing coil (IX/A2) to magnetize them, and then place them on top of the pivot.

Note the ends of the needles which point to the North, and mark these (e.g., with paint).

c. Notes

(i) The galvanometer should be set so that the plane of its coil is in a North-South direction, as indicated by the compass needle. A current passing through the coil will cause the needle to be deflected out of this plane, the angle of deflection depending on the strength of the current.

(ii) It is important that magnets and iron should be kept well away from the galvanometer during use to avoid influencing the compass needle.

(iii) The galvanometer will readily detect the differences in magnitude of currents produced by the various combinations of plates and electrolytes in the Chemical Cell (VIII/A1).

B2. Tangent Galvanometer with Shunts *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base	1	Wood (A)	10 cm x 10 cm x 1 cm
	2	Bolts (B)	0.3 cm diameter, 2.5 cm long
	4	Nuts (C)	0.3 cm internal diameter
(2) Coils	2	Wood (D)	8 cm x 5 cm x 0.5 cm
	2	Wood (E)	3 cm x 5 cm x 0.5 cm
	1	Magnet Wire (F)	#26 (diameter 0.05 cm), length approx-imately 16 meters
	--	Masking Tape (G)	--

*Adapted from Fr. George Schwarz, A Don Bosco Laboratory Manual, (Philippines: Unpublished Papers).

Component	Qty	Item	Specification
(3) Magnetic Needle Assembly	1	Needle (H)	10 cm long, 0.1 cm diameter
	1	Razor Blade with Double Edges (I)	--
	1	Glass Tube (J)	6 cm long, 0.5 cm external diameter
	2	Screws (K)	1.5 cm long
	1	Cardboard Sheet (L)	2.5 cm x 2.0 cm
	1	Pin (M)	2.5 cm long, approximately
	3	Cardboard Sheets (N)	8 cm x 4 cm
(4) Shunts	1	Nichrome Wire (O)	#24, 0.17 ohms (approximately 5 cm long)
	1	Resistor (P)	1,000 ohms (from radio shop)
	1	Bolt (Q)	0.3 cm diameter, 2.5 cm long
	1	Nut (R)	0.3 cm internal diameter

b. Construction

(1) Base

Drill two holes (diameter 0.3 cm) in Wood (A) about 3 cm apart and close to one edge to take the terminals. Use bolts (B) and nuts (C) to make two terminals as described under VIII/A2, Component (4), and fit them through the holes in the base. The boltheads should be countersunk into the bottom of the base so that the latter sits flat on any horizontal surface.

(2) Coils

Make a wooden form using wood (D) for the top and base and wood (E) for the side pieces. Glue the pieces together.

Drill a hole (1.0 cm diameter) in the middle of the top, and an identical hole (1.0 cm diameter) directly beneath in the middle of the base of the form.

Wind magnet wire (F) around the form to make two coils which are connected in series to one another, and which are wound in the same direction around the form. Wind 20 turns of wire into each coil, and locate these close to the opposite edges of the form. Make sure that about 10 cm of each end of the wire is left free. After winding the coils, cover the final layer of turns with a layer of masking tape (G) to hold the coils in position.

Drill two appropriate holes through the base in order to attach the coil form to the base with screws, but do not screw the form on to the base yet.

(3) Magnetic Needle Assembly

Drill a hole (0.1 cm diameter) in the base in the position that corresponds to center of the larger hole in the base of the coil form. Cut the end (containing the eye) off needle (H) to make it 8 cm long, and set the blunt end of the needle firmly in the hole in the base, so that it stands vertically with the point upwards. A little epoxy resin may be required to hold the needle firmly in the hole.

Take a double-edged razor blade (I) which contains a center hole, and magnetize it with the help of a magnetizing coil (IX/A1). Measure the size of the center hole (probably about 0.5 cm diameter), and take a glass tube (J) with the same external diameter as that of the center hole. Heat close (CHEM/I/D5) one end of the tube and create flanges (CHEM/I/D7) at the open end. The flanges on the tube will prevent the razor blade from slipping off the tube, so long as the latter is held in a vertical position.

To put the magnetic needle assembly together, hold the razor blade horizontally inside the coil form. Insert the glass tube through the base hole in the form, and then through the hole in the blade.

Lower the blade onto the flanges of the glass tube, and raise the tube partially through the upper hole in the form.

Lower the coil form and tube together onto the needle projecting vertically from the base. Take two screws (K) and firmly attach the base and coil form together.

Connect the loose wires from the coils to the terminals, making sure that all enamel has been removed from the wire ends.

Take the thin sheet of cardboard (L), and thrust pin (M) through the sheet at about 0.5 cm from the middle of the top edge. Bend the cardboard around the glass tube (J) to form a tight cylinder from which the full length of the pin will protrude. Fasten the free ends of the cardboard sheet together with masking tape wrapped around the cylindrical sheet.

Lower the cardboard cylinder onto the tube until it touches the razor blade. The pin should clear the top of the form by about 0.5 cm, and will serve as a pointer to record the motion of the magnetized needle below.

Cut a semicircular disc (diameter 8 cm) out of the cardboard sheet (N), and set it on top of the coil form to serve as a scale. Mark the position of the cardboard on top of the form, so that the cardboard scale may be replaced in exactly the same position whenever it is removed.

(4) Shunts

Set the plane of the galvanometer coils in a North-South direction so that the longitudinal, horizontal axis of the magnetized razor blade is in the same plane as that of the coils. The direction of the pointer should be set at 90° to this plane. Now calibrate the galvanometer by placing it in series with a milliammeter (0-100 milliamps), a voltage supply (dry cells, battery, etc.) and a variable resistance. The resultant scale will swing from the center zero position of the pointer through about 90°. If the direction of the current through the coil is reversed, a deflection (and hence scale) in the opposite direction will be obtained.

Take a suitable length of nichrome wire (0) and connect it across the galvanometer terminals. In this case, since the resistance of the galvanometer is 1.5 ohms a wire of resistance 0.17 ohms (5 cm of #24, U.S. Standard Plate guage, nichrome wire, 20% chrome, 80% nickel) would result in 1000 milliamps (1 amp) producing a full scale deflection instead of 100 milliamps doing this.

Top View

With the resistance wire across the terminals recalibrate the galvanometer in the usual way with a fresh cardboard sheet for a new scale.

To convert the galvanometer to a voltmeter, add a 1,000 ohm resistor (P) in series to the galvanometer. To do this use bolt (Q) and nut (R) to make a terminal as described under VIII/A2, Component (4), and add it to the base between the existing terminals. Then connect the resistor (obtained from a radio shop) across two adjacent terminals as illustrated. Recalibrate the modified galvanometer by placing it in parallel across a variable resistance, and comparing the potential at any moment with a commercial voltmeter, also placed in parallel with the variable resistance.

V_{AB} = 0.15 volts

V_{AB} = 100 volts

Without a resistance in series, the full-scale deflection of the galvanometer would only measure 0.15 volts across the terminals. With the 1,000 ohm resistance in series, the full-scale deflection of the galvanometer would measure 100 volts across the terminals. More important, the current taken through the galvanometer, compared with that in the circuit being measured, would be negligible.

c. Notes

(i) The resultant scales will be nonuniform, sensitivity falling off with increasing voltage as indicated. The scale will indicate the direction of the current through the galvanometer.

(ii) The galvanometer cannot measure AC current.

(iii) This galvanometer is relatively simple to make, it is surprisingly sensitive, and in combination with the shunts may be used for a wide range of measurements of amperage and voltage.

C. FUNCTIONAL MOVING COIL GALVANOMETERS

C1. Moving Coil Galvanometer ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Base with Upright	1	Wood (A)	14 cm x 11 cm x 1 cm
	1	Wood (B)	6 cm x 11 cm x 1 cm
	2	Wood Screws (C)	2 cm long

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(2) Terminals and Adjustment Screw	2	Brass Bolts (D)	0.3 cm diameter, 2.0 cm long
	4	Nuts (E)	0.3 cm internal diameter
	1	Bolt (F)	0.2 cm diameter, 2 cm long
	1	Nut (G)	0.2 cm internal diameter
	2	Thumbtacks (H)	--
(3) Magnet	1	Horseshoe Magnet (I)	Separation of poles between 3.0 cm and 3.5 cm
(4) Moving Coil	1	Wooden Dowel (J)	2 cm diameter, 3 cm long
	1	Galvanized Wire (K)	7.5 cm long, 0.1 cm diameter
	1	Needle (L)	0.1 cm diameter, 5 cm long
	1	Box of Nails (M)	2 cm long, diameter as small as possible
	1	Roll of Magnet Wire (N)	#22
	2	Pieces of Magnet Wire (O)	#30, 50 cm long
	1	Wood Screw (P)	0.8 cm long
	1	Brass Strip (Q)	3.5 cm x 1.0 cm x o.05 cm
	1	Wood Screw (R)	0.8 cm long
(5) Scale	1	White Paper (S)	10 cm x 10 cm

b. Construction

(1) Base with Upright

Side View

Attach the wooden upright (B) to the base (A) with two screws (C) from beneath the base and with wood cenent to make a firm joint. Leave approximately 2 cm behind the upright.

(2) Terminals and Adjustment Screw

Top View

Make two terminals in the front of the base from the brass bolts (D) and nuts (E) [See VIII/A2, Component (4)].

Make an adjustment screw [as described under IX/A3, Component (1)] from the bolt (F) and nut (G) to fit in one side of the base. At opposite corners of the other side of the base, insert two thumbtacks (H) to the bottom so that the base is rested on three points, the adjustment screw and thumbtacks.

(3) Magnet

Obtain a strong horseshoe magnet (I) in which the separation of the two sides of the horseshoe is approximately 3 cm (or a little more). Make slots in the upright (B) as illustrated to allow the magnet to be pushed through the upright so as to protrude a distance of 2 cm. Once the moving coil (below) has been fixed finally in position, fix the magnet firmly in the upright with epoxy resin. The slots are most easily made before the upright has been screwed to the base.

(4) Moving Coil

Make an inset (0.5 cm wide, 0.5 cm deep) around the wooden dowel (J) specifically to hold a coil. Drill a hole (0.8 cm diameter) along the axis to take the pivot and soft iron core.

Bore a hole (0.5 cm deep, 0.1 cm diameter) horizontally into the bottom of the core at right angles to the plane of the inset (and coil).

Then, fit the galvanized wire (K) into the hole with epoxy resin to serve as a pointer.

The needle (L) will serve as a pivot. Cut off the heads of the nails (M), and make the length 2 cm. Pack the nails into the hole through the middle of the wooden core (J), placing the needle (L) in the very center of the hole, so as to protrude an equal distance from either end of the core. Bind the newly created core and pivot firmly in position with a liberal coating of epoxy resin over the nail ends and around the needle.

Wind 40 turns of magnet wire (N) around the inset of the core, making sure that both ends are left free. Clean the ends of the wire with sandpaper and solder each end on to another length of very fine magnet wire (O) from which fine spring coils may be made around the top and bottom portions of the pivot.

The sensitivity of the spring increases as the number of turns wound into the spring increases, and as the diameter of the spring increases. Once each spring has been wound, avoid subsequent damage during construction by holding it between two pieces of cardboard which may be taped to the wooden core.

Insert the wood screw (P) into the base at a point 2 cm from the front of the upright and centered. Drill an inset (0.2 cm deep) into the head of the screw so that it will serve as a lower pivot for the coil.

Bend the strip of brass (Q) to form an "L" shape. Drill a screw hole (diameter 0.3 cm) in the short end and a pivot hole (diameter 0.2 cm) at a distance of 0.5 cm from the other end. Slide the strip over the pivot needle, and screw the strip to the upright, with the screw (R).

Side View

Connect the wire from the two ends of the springs to the two terminals. One of the best ways of doing this is to drill small holes in the upright (opposite the springs) threading the wire through the holes. If two more holes are drilled through the upright near the bottom (one on either side) the wire may be threaded back through the upright to the terminals.

(5) Scale

Cut a sheet of paper (S) and paste it on the base. Taking the lower pivot as the center point, mark off a scale to indicate every 10^o movement of the pointer. The scale may later be recalibrated in amps or volts as desired.

c. Notes

(i) Should there be any difficulty in obtaining a suitable, strong horseshoe magnet, then multipurpose coils may be used as described in the next item.

C2. Moving Coil Galvanometer with Multipurpose Coils ©

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Basic Apparatus	1	Moving Coil	X/C1, all components except component (3)
(2) Multipurpose Coils	2	Multipurpose Coil with Cores (B)	IX/A2
(3) Coil Holders	4	Brass Sheets (C)	3.0 cm x 0.8 cm x 0.05 cm
	4	Screws (D)	0.8 cm long
	2	Brass Sheets (E)	2 cm x 2 cm x 0.02 cm
	4	Screws (F)	0.8 cm long

© From Reginald F Melton, Elementary, Economic Experiments in Physics, Apparatus Guide, (London: Center for Educational Development Overseas, 1972), pp 159-161.

(4) Terminals and Wiring	2	Brass Bolts (G)	0.3 cm diameter, 2 cm long
	4	Nuts (H)	0.3 cm internal diameter
	1	Roll of Magnet Wire (I)	#24

b. Construction

(1) Basic Apparatus

Make the moving coil galvanometer as described under X/C1, but do not make component (3) of the item or the holes in the upright to take a magnet. The finished product will in fact be the basic apparatus (A).

The subsequent making of the coil holders and addition of further terminals to the basic apparatus is likely to damage the moving coil springs unless these are carefully protected. It is therefore suggested that the springs be held between cardboard sheets taped to the wooden core while further modifications are made.

(2) Multipurpose Coils

Make two multipurpose coils (B) complete with soft iron cores and pole heads as described under IX/A2.

(3) Coil Holders

Cut four clip holders from the four brass sheets (C), making a screw hole at one end and a small slit at the other. Fit the four slits in the holders under the locking nuts of the four terminals of the multipurpose coils (B). Then position each coil in turn on the upright so that the pole head is at exactly the same height above the base as the moving coil core. In this position screw the clips firmly onto the edge of the upright with the screws (D).

Front View

Make two spring holders from the two brass sheets (E) and slip these on the free ends of the multipurpose coils to determine where they should be attached to the upright. Having marked in the position, screw the

holders onto the upright with the remaining screws (F).

(4) Terminals and Wiring

Use the bolts (G) and nuts (H) to make two additional terminals as described under item VIII/A2, component (4). Attach them to the base, just behind the upright, and then connect the clips and terminals with magnet wire (I) so that electrical connections exist between points A to A, B to B, C to C, D to D and E to E, thus insuring that once the additional terminals are connected to a circuit, the resultant current will flow through the two coils in the same direction.

c. Notes

(i) Changing the direction of the current through the moving coil will change the direction of the deflection, so long as the current through the multipurpose coils remains in the same direction. The resultant scale is thus a center zero scale, with the deflection indicating the direction of the current. So long as the current through the moving coil and the multipurpose coils are independent of one another, this galvanometer cannot measure AC current.

(ii) The galvanometer may be calibrated in the usual way by placing it in series with an ammeter (0 → 2 amps), a voltage supple (cells, battery, etc.) and a variable resistance.

(iii) With a current of 0.25 amps flowing through the multipurpose coils, the galvanometer constructed had a range of 0 to ± 1.5 amps. When the current through the multipurpose coils was doubled to 0.50 amps the galvanometer was much more sensitive, and the same deflections produced a range of 0 to ± 0.85 amps.

C3. Moving Coil Galvanometer with Shunts *

a. Materials Required

Components	Qu	Items Required	Dimensions
(1) Support	1	Wood (A)	15 cm x 10 cm x 2 cm
	1	Wood (B)	38 cm x 5 cm x 2 cm
	1	Wood (C)	10 cm x 1 cm x 1 cm
	1	Screw (D)	2.0 cm long

*Adapted from Fr. George Schwarz, A Don Bosco Laboratory Manual, (Philippines: Unpublished Papers).

(2) Electromagnet	1	Soft Iron Bar (E)	18 cm x 2.5 cm x 0.3 cm
	--	Masking Tape (F)	--
	1	Bolt (G)	0.3 cm diameter, 4 cm long
	1	Nut (H)	0.3 cm internal diameter
	1	Wing Nut (I)	0.3 cm internal diameter
	1	Magnet Wire (J)	#26 (0.05 cm diameter), 150 g
	1	Bolt (K)	0.4 cm diameter, 3 cm long
	2	Nuts (L)	0.4 cm diameter
	2	Bolts (M)	0.3 cm diameter, 3.5 cm long
	4	Nuts (N)	0.3 cm internal diameter
	4	Thumbtacks (O)	--
(3) Moving Coil	--	Washers (P)	0.6 cm internal diameter, 1.2 cm external diameter
	1	Wooden Dowel (Q)	0.6 cm diameter, 5.5 cm long
	2	Needles (R)	0.1 cm diameter
	1	Wooden Dowel (S)	3.0 cm diameter, 3.5 cm long
	1	Magnet Wire (T)	#26, 800 cm long
	2	Magnet Wire (U)	#30, 16 cm long
	1	Eye Screw (V)	--
	1	Magnet Wire (W)	#26, 7 cm long
(4) Pointer and Scale	1	Soca Straw (X)	5 cm length
	1	Cardboard Sheet (Y)	6 cm x 5 cm

b. Construction

(1) Support

Use wood (A) for the base. Drill two screw holes in the base and attach a wooden upright (B), as indicated, with the help of screws and glue. Make a slot 1 cm wide, and 1 cm deep, in the top of the upright to hold wood (C), the wire support. Drill a hole (0.2 cm diameter) at one end of the support, so that the latter may be attached to the upright by means of a screw, and drill another hole (0.4 cm diameter) at the other end of the support to take a bolt. Attach the wire support to the upright with the help of the screw (D) and glue.

(2) Electromagnet

Bend the soft iron bar (E) into a "U" shape with the parallel sides 4 cm apart.

Wrap a layer of masking tape (F) around the bent bar, leaving the ends (3 cm lengths) clear. The tape will prevent the subsequent magnet wire from being scraped and bared on any sharp edges. Bore a hole (0.3 cm diameter) in the middle of the base of the U-shaped bar.

Insert the bolt (G) through the hole, and attach it firmly to the bar with the nut (H). Wrap about 150 g of magnet wire (J) around the covered portion of the bar to make an electromagnet coil. Leave about 40 cm of free wire at either end of the coil. Cover the final layer of magnet wire with masking tape (F) to hold it firmly in position.

Drill a hole (0.3 cm diameter) through the middle of the upright, and attach the newly made electromagnet to the upright with the help of the protruding bolt and wing nut (I).

Side View

Drill a small hole (0.2 cm diameter) through the end of the bolt (K) furthest from the head. Insert the bolt through the hole in the end of the wire support, and hold it in position with two nuts (L) as illustrated.

Drill two holes (0.3 cm diameter) into the front of the base. Make two terminals from the nuts (N) and bolts (M) as described under item VIII/A2, component (4). Set the terminals into the holes, making sure they are inset into the bottom of the base, thus leaving the bottom perfectly smooth.

Fasten one of the wires from the electromagnet to a terminal on the base, and the other wire from the electromagnet to the bolt (K) on the wire support. Make sure the enamel has been removed from the wire ends prior to connection. Use thumbtacks (O) to hold the wires in position on the upright.

(3) Moving Coil

Slide the washers (P) onto the middle of the wooden dowel (Q). Add the washers until they make a stack 3.5 cm long on the middle of the dowel. Use epoxy resin to fix the washers in position. Drill a hole (0.1 cm diameter, 1 cm deep) into either end of the dowel. Cut two 2 cm lengths off the eye ends of the two needles (R), and insert these into the newly drilled holes (needle eyes projecting). Fix them firmly in position with the help of epoxy resin.

Cut a groove (0.5 cm deep, 1 cm wide) around the wooden dowel (S) to hold the subsequent magnet wire coil in position. Drill a hole (1.2 cm diameter) along the axis of the spool, and insert the newly made stack of washers on the dowel (Q). Use epoxy resin to hold this firmly in position within the dowel.

Take the magnet wire (T) and wind it around the dowel (S) to make a rectangular coil contained within the groove which was cut for this purpose. Bare the ends of the wire, and wrap them around the stem of the top and bottom needles (R) respectively, insuring good electrical contact between magnet wire and needle.

Bare one of the ends of the magnet wire (U) and wrap it around the eye of the needle in the top end of the dowel (S). Suspend the dowel and coil by the wire, so that the dowel hangs between the pole ends of the electromagnet. With the dowel in this position, fasten the other end of the magnet wire to the hole in the bolt in the wire support (after cleaning the end of the magnet wire).

Take the second length of magnet wire (U) and attach one end (after cleaning) to the eye of the needle in the bottom of the dowel (S). Insert an eye screw (V) in the base, directly beneath the dowel, and connect the other end of the magnet wire (bared) to the screw. The slack should be taken out of this bottom magnet wire.

Connect the eye screw to the unused terminal in the base by means of the remaining length of magnet wire (W).

(4) Pointer and Scale

A pointer for the galvanometer may be made from a soda straw (X). Make a small slit in the end, and fit it around the eye of the needle at the top of the dowel (S). A little glue will hold it firmly in position.

To make the scale, bend the 5 cm end of cardboard (Y) at 90^0 to make a 1 cm flap, and a flat surface 5 cm x 5 cm. Attach the cardboard to the upright (immediately beneath the pointer) with glue placed between the cardboard flap and the upright.

c. Notes

(i) The galvanometer may be calibrated by placing it in series with an ammeter (0 - 1 amp), a voltage supply (dry cells, battery, etc.) and a variable resistance. The resultant scale will not be uniform.

(ii) Changing the direction of the current through the moving coil changes the direction of the current through the electromagnet. As a result, the deflection of the pointer is always in the same direction, regardless of the direction of the current. The galvanometer thus measures AC and DC current equally well. (This would not be the case if a permanent magnet was used instead of the electromagnet.)

(iii) Strictly speaking, the earth's magnetic field should be taken into consideration in using this galvanometer. For most purposes in the

secondary school, this confounding factor may be ignored. Hence, in calibrating the galvanometer it is useful to set the zero position of the coil at an angle to the line between the pole heads of the electromagnet, thus making full use of the scale.

DC Amps

DC Amps

(iv) The resistance of the galvanometer is 1.8 ohms. Hence, if a shunt of 0.2 ohms is placed in parallel with the galvanometer, the scale of the latter will be multiplied by 10. The full scale deflection will thus correspond to 5 amp instead of 0.5 amp. Such a shunt may be made from a length of nichrome wire (approximately 5 cm of #24 nichrome, 20% chrome and 80% nickel) connected between the terminals of the galvanometer.

0.2 Ω
Shunt

Top View
(Cross-section)

(v) If a 250 ohm shunt is added in series to the galvanometer, it may be used as a voltmeter, the full-scale deflection corresponding to 125 volts (DC). One way of conveniently doing this is to add a third terminal [see VIII/A2, component (4)] to the front of the galvanometer base, simply placing the shunt (obtained from a radio shop) across two adjacent terminals.

Top View
(Cross-section)

The modified galvanometer may then be calibrated by placing it in parallel across a variable resistance, and comparing the potential at any moment with that indicated by a commercial voltmeter, also placed in parallel across the variable resistance.

BIBLIOGRAPHY

A number of texts have proved to be extremely valuable references to the Inexpensive Science Teaching Equipment Project, and these are listed below.

American Peace Corps, Science Teacher's Handbook, (Hyderabad: American Peace Corps, 1968).

This is a clear, well presented book which indicates how apparatus may be constructed for use in biology, chemistry, and physics classes at an introductory level.

The Association for Science Education, Science Master's Book, Part I of Series I to IV, Physics, (London: John Murray).

The material for this series has been selected from the School Science Review, which is published quarterly by the Association for Science Education. It contains details of the construction of many items of equipment, and describes related experiments for use in physics classes at the secondary level.

Association for Science Education, The School Science Review, (London: John Murray).

This is a quarterly journal which describes the construction of apparatus which may be used in the teaching of science at all levels.

Bulman, A.D., Model Making for Young Physicists, (London: John Murray, 1963).

This is a useful book which indicates how students might make some 30 items of physics equipment.

Bulman, A.D., Experiments and Models for Young Physicists, (London: John Murray, 1966).

This publication is on similar lines to the author's book indicated above, and contains descriptions of a further 18 items of equipment.

Joseph, A., P.F. Brandwein, E. Morholt, H. Pollack and J.F. Castka, A Sourcebook for the Physical Sciences, (New York: Harcourt, Brace & World, Inc., 1961).

This book offers not only a wide range of construction ideas, but also a whole series of suggestions for projects and experiments.

Melton, Reginald F., Elementary, Economic Experiments in Physics, (London: Centre for Educational Development Overseas, 1972).

This is a four volume publication which provides not only details of apparatus construction and related experiments, but also provides much detailed information concerning laboratory and workshop facilities. It is intended for use at the secondary level in developing countries.

Merrick, P.D., Experiments with Plastic Syringes, (San Leandro, California: Educational Science Consultants, 1968).

This book and the accompanying materials form a good basis for developing curriculum materials based on the disposable plastic syringe.

Richardson, J.S. and G.P. Cahoon, Methods and Materials for Teaching General and Physical Science, (New York: McGraw-Hill Book Company, Inc., 1951).

This book contains a wide range of ideas for the making of physical science equipment, and includes many related suggestions concerning techniques, skills and procedures.

Stong, C.L., The Scientific American Book of Projects for the Amateur Scientist, (New York: Simon and Schuster, 1960).

The contents of this book are selected from Mr. Stong's clearing house of amateur activities, appearing monthly in Scientific American, and cover a wide range of experiments and related apparatus construction for all fields of science.

United Nations Educational, Scientific and Cultural Organization, UNESCO Source Book for Science Teaching, (Paris: UNESCO, 1962).

This is one of the best resource books available for the construction of simple inexpensive science teaching equipment for use at all levels of teaching.

In addition to the above texts the materials from a large number of projects in the files of the International Clearinghouse on Science and Mathematics Curricular Developments at the University of Maryland have also been particularly valuable. Further details of these projects may be found in:

The Seventh Report of the International Clearinghouse on Science and Mathematics Curricular Developments 1970, (Maryland, U.S.A.: University of Maryland, College Park, 1970).

This is a source of information on curriculum projects throughout the world, and indicates materials available, project directors, publishers, etc. The Eighth Report will be available in late 1972.

ALPHABETICAL INDEX